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# CHEMISTRY
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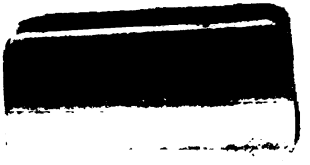

# CHEMISTRY

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## PLATE I.

THE TYPICAL ACIDIC ELEMENTS FROM WHICH THE "BONDS" ARE DEDUCED.

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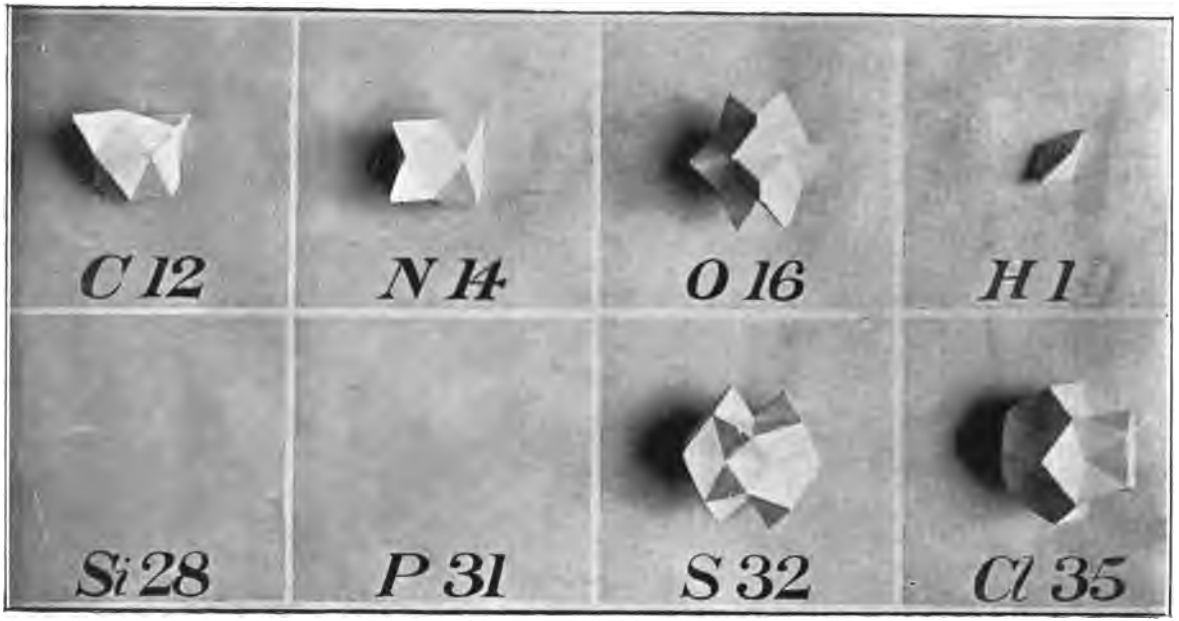

# CHEMISTRY

## AN EXACT

## MECHANICAL PHILOSOPHY

BY

FRED. G. EDWARDS

INVENTOR OF ATOMIC MODELS

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LONDON

J. & A. CHURCHILL

7 GREAT MARLBOROUGH STREET

1900

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# PREFACE.

THE object of this work is to determine the exact shape of the atoms, to find their relative positions in space, and to show that chemical force is purely a function of matter and motion.

Chapter II., "The Existing Molecular Theory Untenable," I believe to be an argument that will effectually refute the prevalent conception of molecules as atoms held intimately together by some "occult" force.

The shapes obtained for the different atoms (Chapter III.) is the subject-matter of a British patent (Atomic Models) dated 1897. The exact agreement in the following points should convince the most sceptical of the truth of this discovery:

1. The recurring shapes of the atomic models agree with the periodicity of the elements.
2. Twelve inverse pyramidal faces predominate just so far as the particular atom is acidic in characteristics.
3. Projecting pyramidal faces predominate just so far as the particular atom is metallic in characteristics.
4. The sudden change from acidic to metallic models at the points between chlorine and potassium, bromine and rubidium, iodine and cæsium respectively.
5. The formation of the basic and acidic oxides.

85331

6. The absolutely perfect relationship of the atomic shapes of the organic elements; and the hypothetical bonds of the same representative elements, carbon, nitrogen, oxygen, and hydrogen, mechanically accounted for.
7. The formation of such complicated molecules as aurin or tri-phenyl-methane with every bond mechanically accounted for.

The relative positions in space of the atoms in the whole of the known compounds of inorganic and organic chemistry can undoubtedly be deduced therefrom. The acidic and basic oxides and hydrides, the simpler inorganic salts, and the mother-substances of the more important organic compounds are herein delineated. There can hardly be more than two fundamentally different arrangements in space (the liquid or solid, and the gaseous) for the atoms of any well-defined compound, as our empirical knowledge is so intimate, and, consequently, the conditions for every atom so exacting. Therefore, having once obtained formations corresponding to these conditions for a large system of compounds, it is reasonable to deduce the absolute truth of the assumed premises regarding the shapes of the atoms of carbon, nitrogen, oxygen, and hydrogen, which form the representative compounds.

A simple test of the truth of these speculations may be made by minutely examining the structure obtained for water in its liquid and gaseous forms and in combination with acids and alkalies, noting the relative weight of the oxygen and hydrogen atom, the relative gaseous volume of the simple compound and the individual " bonds " of each element. I cannot conceive a more perfect coincidence as possible.

The conclusions herein deduced (when accepted as true) will form a fitting climax to the discoveries of a century which has produced the atomic theory of Dalton, the theory of heat as a mode of motion, and the discoveries of the correlation of physical forces, and that force like matter is indestructible.

The materialist may reduce everything to atoms or atomets whose function it is to occupy space, but there his inquiries cease, as the observing faculties of the mind, on which he relies, fail him. No further mechanical reduction is possible. Is not this where the true province of spiritualism begins? Imponderable ether, and, consequently, the ether theory of light and electricity, and also gravity as an occult force, must be placed to the credit of spiritualistic thought, as the usual conception of an ethereal substance has one insuperable objection :—if it effectually occupies space it is matter, but if it does not effectually occupy space (and this it can only do atomically), it is totally incapable of moving a material atom, whether under the influence of light, electricity, or gravity.

It is hoped, in spite of the original character of this work, that it will be found useful for chemical students. Many difficult problems are presented from a quite unusual standpoint, so that if read together with the ordinary text-book the underlying principles of chemistry will be the more easily grasped. No general description of chemical nomenclature is given, but as far as possible the chemical formula is given in brackets wherever the name of a compound is used. The demonstrations are chiefly geometrical, and may be thoroughly comprehended by the technical man.

It is impossible to present the established laws of chemical

philosophy in any really new form, so in Chapters II. and IV. I have taken the usual tables from Professor Tilden's edition of Watts' Inorganic Chemistry, and those relating to the molecular heat of compounds and to gaseous diffusion from Professor Newth's Inorganic Chemistry, in some cases with slight adaptation; and have also compiled my own tables relating to metallic compounds (Chapter VI.) from the same works.

FRED. G. EDWARDS.

*January* 1900.

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# CHEMISTRY

## AN EXACT MECHANICAL PHILOSOPHY

### CHAPTER I.

### INTRODUCTION.

MATERIALISM, originating with the atomical philosophy, has produced the atomic theory, the kinetic theory of gases, the theory of heat as a mode of motion, and the discoveries of the correlation of physical forces and that matter and force are indestructible. These products of materialistic thought, properly understood, are natural corollaries of the atomic theory. It will be shown by pure reasoning that all matter can be finally resolved into indestructible atoms or atomets; that is to say, the seventy known elementary atoms of the chemists can be reduced to one primordial material whose atom is a tetrahedron the sole function of which including the property of elasticity is to occupy effectually an infinitesimal space. The atoms of each elementary substance are built up from this material.

In dealing with the motions of the atoms a difficulty arises from the fact that they have hitherto been supposed to move together in groups or molecules of one, two, three, or more held together by some "occult" force. An "occult" force is a term without any practical meaning to the materialist, who would prefer to say that the atomic motions had not yet been properly investigated so as to account for the various phenomena of chemical reactions. It will be shown herein that all

intestine motion of solids, liquids, and gases, is purely atomic, and molecular motion purely a function or product of atomic motion. This fact will much simplify further investigation.

The capacity for heat of an elementary substance varies inversely with the atomic weight, so that if quantities of different substances be taken in the proportion of their atomic weights the resulting specific heats come out very nearly equal. The specific heat of a body denotes the *amount* of heat required to raise the temperature 1° C. (at the standard temperature), compared with that required for an equal weight of water. That iron, for instance, has a greater capacity for heat than copper or lead is shown by the following experiment: If three balls of the different metals are heated to the same temperature (by immersing them in hot oil) and then placed on a suspended cake of bees-wax they will melt their way through at different rates, the iron ball first, the copper next, and the lead last. Water is accepted as the standard for specific heat as it possesses a greater capacity for heat than any other substance.

The kinetic theory of gases is founded on observations of the variation of volume and pressure of gases at different temperatures. When a given quantity of any perfect gas is maintained at a constant volume it tends to expand by $\frac{1}{273}$ of its bulk at zero for each degree Centigrade through which it is heated, and therefore the consequent pressure on the containing vessel increases proportionately to the temperature. Hitherto it has been supposed that this pressure is caused by the impact of molecules constantly moving in straight lines, each molecule being an aggregate of atoms. But it will be shown that it is caused by the impact of atoms, the path of the atom in the gas being different to that in a liquid or solid. A connection will thus be established between the kinetic theory of gases and the specific heat of solids, liquids, and gases. It will henceforth be evident that heat is *atomic* motion also.

The doctrine of the correlation of physical forces is now

accepted as a postulate in natural philosophy. It maintains that all the forces of nature—heat, light, electricity, chemical affinity, and motion—are convertible into each other. Joule established the fact that to raise the temperature of 1 lb. of water 1° F. requires the expenditure of as much work as would raise 772 lbs. 1 foot, and 772 foot-pounds is, therefore, known as the mechanical equivalent of heat. Similarly, a measured amount of heat may be converted into chemical affinity, which may be again recovered as heat when the combination is broken up. This places the spiritualist in a peculiar difficulty. If the atoms of a molecule are held together by an "occult" force, that "occult" force is first produced from atomic motion, and, again, that same "occult" force itself produces atomic motion, which is absurd if the "occult" force be not atomic motion also. It will be shown that chemical changes are purely functions of atomic motion.

The materialist will be content, after finding the exact shape of the different atoms, to trace, so far as he is able, their motions through all natural phenomena. The fact that matter and force are indestructible simply means to him that the atom cannot be damaged or destroyed and that motion can only be taken from it by imparting it to other atoms.

A regular solid is one that can be inscribed with all its points in the surface of a sphere. The five regular solids are the tetrahedron, the octahedron, and the icosahedron (with four, eight, and twenty triangular faces respectively), the cube and the dodecahedron. The regular dodecahedron has twelve pentagonal faces.

The rhombic dodecahedron, with twelve rhombic faces, can be compared with the pentagonal dodecahedron in Fig. 2 (p. 30). The rhombohedron is a solid with six rhombic faces, and is really a distorted cube. The rhombic dodecahedron (likewise the rhombohedron) is a solid which exactly fills space when a number are placed together with coincident faces. By noting and numbering the solid angles it will thus be possible to plan out space in three dimensions at once.

## CHAPTER II.

### THE EXISTING MOLECULAR THEORY UNTENABLE.

*The molecules of all gases, simple or compound, occupy equal volumes; or equal volumes of all gases contain equal numbers of molecules.* This law of Avogadro is the result of careful observation and measurement of gaseous volumes, and is worded so as to exclude every possible source of error. It is absolutely true. But the prevalent conception of molecules founded on this law is not so true. Molecules are assumed to be a number of atoms held more or less intimately together by some force of attraction inherent in themselves so that they move collectively as one body. But by comparing the specific heats of elements and simple compounds this will be shown to be an impossible assumption.

The densities of most of the elements which exist in the state of gas or vapour are proportional to their atomic weights, but phosphorus, arsenic, zinc, cadmium, and mercury are exceptional, as shown by the relative atomic density in the following table:

| Monatomic. | Diatomic. | Tetratomic. |
|---|---|---|
| Zn | $H_2$ | $P_4$ |
| Cd | $K_2$ | $As_4$ |
| Hg | $Cl_2$ | |
| | $Br_2$ | |
| | $I_2$ | |
| | $F_2$ | |
| | $O_2$ | |
| | $N_2$ | |
| | $S_2$ | |

This seems to support the theory that the atoms of elementary gases are held intimately together to form molecules of one, two, three, or more; and the theory is apparently confirmed and extended to compound gases also by their relative molecular volumes.

Gay-Lussac observed that the product of the union of two gases, when itself a gas, sometimes retains the original volume of its constituents, no contraction or change of volume resulting from the combination, but that when contraction takes place, which is the most common case, the volume of the compound gas always bears a simple ratio to the volumes of its elements; and subsequent observation has shown that, with few exceptions, *the molecules of compound bodies in the gaseous state occupy twice the volume of an atom of hydrogen gas.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 vol. | H | and 1 vol. | Cl | form | 2 vols. | | HCl | (hydrochloric acid). |
| 1 „ | N | „ 1 „ | O | „ | 2 | „ | NO | (nitrogen dioxide). |
| 2 vols. | H | „ 1 „ | O | „ | 2 | „ | $H_2O$ | (water). |
| 3 „ | H | „ 1 „ | N | „ | 2 | „ | $H_3N$ | (ammonia). |
| 3 „ | H | „ ½ „ | P | „ | 2 | „ | $H_3P$ | (hydrogen phosphide). |

Similarly, in the union of compound gases,

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 vol. | ethyl | $C_2H_5$ | and 1 vol. | | Cl | form | 2 vols. | $C_2H_5Cl$ | (ethyl chloride). |
| 2 vols. | „ | $C_2H_5$ | „ 1 | „ | O | „ | 2 „ | $(C_2H_5)_2O$ | (ethyl oxide). |
| 2 „ | ethylene | $C_2H_4$ | „ 2 vols. | | Cl | „ | 2 „ | $C_2H_4Cl_2$ | (ethylene chloride). |
| 2 „ | „ | $C_2H_4$ | „ 1 vol. | | O | „ | 2 „ | $C_2H_4O$ | (ethylene oxide). |

But the relative atomic and molecular volumes must be otherwise accounted for, as any argument in support of the existing conception of molecules (as a number of atoms intimately joined together) will be entirely refuted by the atomic heats of elementary and compound bodies.

Dulong and Petit observed that the specific heats of the *solid* elements are inversely as their atomic weights; so that

the product of the atomic weight into the specific heat is a constant quantity, and represents the amount of heat contained in a single atom. The number expressing the atomic heat is not perfectly constant, but the departures from the mean 6·4 are as a rule only slight, as shown by the following table:

*Specific Heats of Elementary Bodies.*

| Elements. | Specific heat. | | Atomic weight. | | Atomic heat. |
|---|---|---|---|---|---|
| Lithium . . | ·9408 | × | 7 | = | 6·59 |
| Sodium . . | ·2934 | × | 23 | = | 6·75 |
| Aluminium . . | ·2143 | × | 27 | = | 5·78 |
| Phosphorus liquid | ·2120 | × | 31 | = | 6·57 |
| Phosphorus solid | ·1887 | × | 31 | = | 5·85 |
| Sulphur . . | ·2026 | × | 32 | = | 6·48 |
| Potassium . . | ·1660 | × | 39 | = | 6·48 |
| Iron . . . | ·1138 | × | 56 | = | 6·36 |
| Nickel . . . | ·1080 | × | 59 | = | 6·41 |
| Cobalt . . | ·1070 | × | 59 | = | 6·31 |
| Copper . . | ·0952 | × | 63 | = | 6·00 |
| Zinc . . . | ·0956 | × | 65 | = | 6·21 |
| Arsenic . . | ·0822 | × | 75 | = | 6·17 |
| Selenion . . | ·0762 | × | 79 | = | 6·02 |
| Bromine (solid) . | ·0843 | × | 80 | = | 6·74 |
| Palladium . . | ·0593 | × | 106 | = | 6·30 |
| Silver . . . | ·0570 | × | 108 | = | 6·16 |
| Cadmium . . | ·0567 | × | 110 | = | 6·24 |
| Indium . . | ·0570 | × | 114 | = | 6·50 |
| Tin . . . | ·0548 | × | 117 | = | 6·41 |
| Antimony . . | ·0523 | × | 120 | = | 6·28 |
| Iodine . . . | ·0541 | × | 127 | = | 6·87 |
| Tellurium . . | ·0475 | × | 126 | = | 5·98 |
| Gold . . . | ·0324 | × | 198 | = | 6·41 |
| Platinum . . | ·0324 | × | 196 | = | 6·35 |
| Mercury (solid) . | ·0319 | × | 200 | = | 6·38 |

| Elements. | Specific heat. | | Atomic weight. | | Atomic heat. |
|---|---|---|---|---|---|
| Thallium . . | ·0335 | × | 204 | = | 6·88 |
| Lead . . . | ·0314 | × | 207 | = | 6·50 |
| Bismuth . . | ·0308 | × | 210 | = | 6·48 |

The specific heats of carbon, boron, silicon, and beryllium appear to be exceptional at ordinary temperatures, but at higher temperatures they become constant, giving for the atomic heats a mean value of about six, which is nearly the same as that of the other elements of small atomic weight like aluminium and phosphorus. Thus:

| | Specific heat at high temperature. | | Atomic weight. | | Atomic heat. |
|---|---|---|---|---|---|
| Silicon (crystal) . | ·1774 | × | 28·0 | = | 4·97 |
| Carbon (diamond) | ·1469 | × | 12·0 | = | 1.76 |
| Boron (crystal) . | ·2500 | × | 11·0 | = | 2·75 |
| Beryllium . . | ·6206 | × | 9·1 | = | 5·60 |

It is therefore concluded that *all elements in the solid state have the same atomic heat;* and as heat and work are convertible, each atom, whether of zinc or sulphur for instance, provided they are at the same temperature, may be said to have the same amount of energy stored up in them. The work stored in an atom is due to its motion, and varies as its mass multiplied into the square of its velocity, so that if its only motion were one of velocity then that velocity would vary for different elements at the same temperature inversely as the square root of the several atomic weights.

By way of parenthesis it may be noted here that the densities of the elementary gases at the same temperature and pressure are, with the exceptions already noted, proportional to their atomic weights, and that an atom (or molecule?) of hydrogen, for instance, has to occupy the same volume as, say, an atom of oxygen, which is sixteen times as heavy. It can only do this by an increase of velocity, so that the *vis viva* of impact of two atoms of hydrogen is the same as

that for two atoms of any other gas of higher atomic weight. The *vis viva*, or twice the energy stored in a moving body, varies as the weight or mass and as the square of the velocity $= MV^2$; so that oxygen, being sixteen times the weight of hydrogen, would move with one-fourth the velocity, and in that case $MV^2 = 16 \times (\frac{1}{4})^2 = 1$, the same as hydrogen, assuming it to have unit weight and unit velocity. An elementary gas being composed of a number of atoms (or molecules) exactly alike in weight and velocity, must almost of necessity, where the temperature and pressure are uniform throughout the mass, have those atoms equally spaced and describing similar paths with similar impacts. It will be found that a proper comprehension of these motions will account for the different states of matter, solid, liquid, and gaseous, and for the relative atomic density of gases, at present explained by considering the molecules as composed of one, two, three, or more atoms held intimately together.

But there is also another fact which apparently supports the prevalent theory of molecules. When two gases are separated by a porous diaphragm, the rate of diffusion varies inversely as the square root of the *density*, whether the gases be elementary or compound, as shown by the following table, the last column of which gives the actual results observed by Graham:

| Name of gas. | Density of gas compared with air = $d$. | $\sqrt{\frac{1}{d}}$ | Volume of gas which diffused in the same time as one volume of air. |
|---|---|---|---|
| Hydrogen | ·06926 | 3·7794 | 3·8300 |
| Marsh gas | ·55900 | 1·3375 | 1·3440 |
| Carbon monoxide | ·96780 | 1·0165 | 1·0149 |
| Nitrogen | ·97130 | 1·0147 | 1·0143 |
| Oxygen | 1·10560 | ·9510 | ·9487 |
| Sulphuretted hydrogen | 1·19120 | ·9162 | ·9500 |
| Carbon dioxide | 1·52900 | ·8087 | ·8120 |
| Sulphur dioxide | 2·24700 | ·6671 | ·6800 |

This is usually explained by assuming the elementary gases, as hydrogen and nitrogen, to be composed of diatomic molecules, $H_2$ or $N_2$, while in the compound gases the molecules are $CH_4$, CO, $SH_2$, $CO_2$, $SO_2$, &c., so that the molecule represents the relative density of the gas. As the gases at the same temperature and pressure occupy equal volumes, the kinetic energy of each molecule is identical, and its velocity varies inversely as the square root of the density, or one-half the molecular weight.

This is apparently a perfect explanation of the phenomena of the diffusion of gases, but that this conclusion is not justified will be found on considering the specific heats of elements and compounds.

Now, if two atoms are intimately joined together to form a molecule, the specific heat of the molecule would be the same as that of one atom equal to the combined weight. In the table on page 4 zinc, cadmium, and mercury are shown to be monatomic in the gaseous condition, while potassium, for instance, is diatomic. In the table on page 6 the atomic heats of zinc, mercury, and potassium are shown to be the same; but the *atomic*, and not the *molecular*, weight has in each case been multiplied into the specific heat to obtain the atomic heat; therefore, whatever may happen in the gaseous condition, at least in the solid state the molecule of zinc, cadmium, and mercury must contain the same number of atoms as potassium or any other element *if they are intimately joined together*, so that they partake of the same motions. The same reasoning will apply to the tetratomic elements, phosphorus and arsenic, each in the solid state, as no variation is found in the specific heats of these elements sufficient to indicate the formation of molecules consisting of a number of atoms moving collectively as one body. Specific heat, therefore, is atomic, and not molecular, motion; and if it can be proved that in the solid, liquid, and gaseous conditions of matter this atomic motion is so considerable as to account for specific heat and also gaseous temperature and pressure as

well as chemical reactions, it will be seen that the molecule is merely an accidental product of these atomic motions, and the relative atomic density and rates of diffusion of gases must be otherwise accounted for.

The capacity for heat of an atom (in a solid) undergoes no alteration when it enters into combination with different atoms in simple compounds. The *molecular heat* of a compound (that is the product of the molecular weight into the specific heat) is therefore the sum of the atomic heat of its constituent elements.

The specific heat of silver chloride, AgCl, is ·089:

| Specific heat. | | Molecular weight. | | Molecular heat. |
|---|---|---|---|---|
| ·089 | × | 143·5 | = | 12·77 |

The atomic heat of silver is 6·1; therefore, as deduced from this compound, the atomic heat of chlorine is 12·77 − 6·1 = 6·6.

Again, the specific heat of stannous chloride, $SnCl_2$ is ·1016:

| Specific heat. | | Molecular weight. | | Molecular heat. |
|---|---|---|---|---|
| ·1016 | × | 189 | = | 19·2 |

The atomic heat of tin is 6·6; therefore the atomic heat of two atoms of chlorine, as deduced from this compound, is 19·2 − 6·6 = 12·6, giving 6·3 as the atomic heat of chlorine.

These calculations give the atomic heat of an element, such as chlorine, in the solid state which does not exist as a solid under ordinary conditions; *but they also lead to a more important conclusion.*

If the atoms of a compound molecule are intimately joined together so that they move as one body the molecular heat of the compound would be the same constant 6·4 as in the case of the elementary bodies; for although the weight of the compound molecule would be greater, its velocity would be correspondingly reduced, so that twice the energy stored would still equal mass multiplied by velocity squared $= MV^2$; but

as each separate atom forming the molecule has the same atomic heat that it had in the elementary state, it follows that *the motion of each atom is still independent and unreduced in the molecule, although by some means it is fixed in position.* Furthermore, as in gases every increase in temperature produces a corresponding increase in pressure on the sides of the containing vessel, it becomes evident that these atomic motions produce that pressure, and the molecular motions are merely products of atomic motion. Therefore the whole of the phenomena of specific heat, gaseous diffusion, gaseous volume, and likewise chemical reactions may be traced solely as the products of atomic motion. Chemical reactions must be included, as they do not take place without the subtraction or addition of an equivalent amount of heat.

The atomic heats of the three elements which are perfect gases (*i.e.*, not easily liquefiable), hydrogen, oxygen, and nitrogen, produce a different constant, 3·4, as shown by the following table:

*Specific Heat of Elementary Bodies (Gases).*

| Element. | Specific heat (Regnault). | | Atomic weight. | | Atomic heat. |
|---|---|---|---|---|---|
| Hydrogen . . | 3·4090 | × | 1 | = | 3·4 |
| Nitrogen . . | ·2438 | × | 14 | = | 3·4 |
| Oxygen . . | ·2175 | × | 16 | = | 3·4 |

This constant, 3·4, for the atomic heat of elements in the perfectly gaseous condition is a little more than one-half the former constant, 6·4, obtained for the elements in the solid state; and as it has just been shown that the atoms in a molecule move independently of each other, it is reasonable to conclude that the path of motion of an atom in the gaseous condition is entirely different from that of the same atom in the solid or liquid condition, and that also there is some simple constant relation between the two paths. This remark need not apply to phosphorus and arsenic, which do

not absorb a large amount of latent heat in passing from the solid to the gaseous condition. There is not a sufficient variation of the specific heats of atoms in the two conditions of solid and liquid to warrant any assumption that their several paths of motion are not practically identical, assuming the liquid to be absolutely quiescent.

That the atoms composing a simple molecule move quite independently of each other is perhaps also indicated by the spectra of some simple compounds of hydrogen which show the three characteristic lines corresponding to the spectrum of pure hydrogen.

These apparently contradictory conclusions will be reconciled in the following chapters by examining well-defined and representative compounds in the solid or liquid and gaseous condition by the help of the assumed shape of the representative atoms, namely, carbon, nitrogen, oxygen, chlorine, and hydrogen. Every atom of a liquid or solid element or simple compound falls inevitably into a more or less dodecahedral space, which it occupies by virtue of its own kinetic energy; while every atom of a gaseous element or simple compound (as HCl) assumes a more or less cubic or octahedral arrangement, corresponding to the six sides and eight corners of a cube. One being a twelve-sided figure and the other a six-sided, one might very well account for the differing constants 6·4 and 3·4 obtained for the atomic heats. If rhombic dodecahedra are symmetrically placed at the corners of the cubic spaces of the gaseous formation, the resulting space within each cube is a similar dodecahedron, and it can be seen that the density of the dodecahedral arrangement is just double that of the cubic. This may be the tetratomic formation of phosphorus and arsenic in the gaseous as well as the solid condition. The apparently monatomic molecules of zinc, cadmium, and mercury in the gaseous condition may possibly be accounted for by the twelve projecting pyramidal faces of these atoms, making the adjacent cubic spaces untenable for like atoms.

## CHAPTER III.

### EXACT SHAPE OF ATOMS.

EVERY advance in science is made by supposition tested by observation and experiment. It will be necessary here to assume a shape for the atom of the lightest known element, hydrogen. Fig. 1 represents such an atom consisting of two tetrahedra placed base to base; and the atoms of the whole of the remaining elements may be similarly formed by tetrahedra built up symmetrically, every two tetrahedra representing one unit of atomic weight. If it is found that the shape of the atoms so formed accounts for their periodicity and acidic and metallic characteristics, and also shows a very subtle relation between carbon, nitrogen, oxygen, and hydrogen, enabling them to form the extraordinarily large number of compounds of organic chemistry; and furthermore, if the hypothetical bonds between the different atoms can be mechanically accounted for, and the relative position in space of every atom in a compound be determined; and, still further, if the solid, liquid and gaseous states of matter can be explained by tracing the paths of these atoms; and, finally, that the whole of these conclusions are inevitable from the one assumption, then it can be reasonably concluded that that assumption is correct. The observation and experiment to test that assumption is already to hand, and a distinct advance, not only in the science of chemistry, but in physics and in general philosophy has been made.

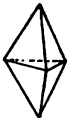

FIG. 1.

The atom remained a purely theoretical conception until

John Dalton published his "New System of Chemical Philosophy" in 1807. He then stated that the atoms of *each* element were incapable of being subdivided, and that each had a definite relative weight compared with that of the lightest known element, hydrogen, as unity. There are now known about sixty-five or seventy such elements capable of combining with each other in certain definite proportions.

The knowledge of atoms became more intimate when Newlands, in 1864, discovered the "Periodic Law," afterwards tabulated by Mendelejeff. The periodic law notes a remarkable relation between the "valency," or combining capacity of these elements, and the numerical order of their atomic weights, as shown in the table on page 15, giving the names of the elements together with their chemical symbols and their atomic weights arranged consecutively in horizontal lines.

The maximum combining capacity of the elements in each of the eight vertical columns with chlorine, oxygen, and hydrogen respectively is indicated by the symbols at the foot of each column, with R to represent the element in question. Chlorine and oxygen form a simple ascending arithmetical series, commencing with the first column, while hydrogen forms a similar descending series, commencing with the fourth column. The combinations with chlorine and oxygen relate more or less to the whole of the elements, but those with hydrogen do not relate to the long horizontal series (numbered 4, 6, 8, and 10), which are all metallic, nor to the commencement of the short horizontal series (numbered 2, 3, 5, 7, and 9), which are also more or less metallic; but the capability of the remainder of each short series under columns III., IV., V., VI., and VII. to unite with the monad element, hydrogen, to form binary compounds marks the gradual transition of the elements from metallic to acidic in their characteristics. In the seventh column (or Group VII.) the halogen elements, fluorine, chlorine, bromine and iodine, unite

| Series | Group I | II. | III. | IV. | V. | VI. | VII. | VIII. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Hydrogen H. 1 | | | | | | | | | | |
| 2. Short | Lithium Li. 7 | Beryllium Be. 9 | Boron B. 11 | Carbon C. 12 | Nitrogen N. 14 | Oxygen O. 16 | Fluorine F. 19. | | | | |
| 3. Short | Sodium Na. 23 | Magnesium Mg. 24 | Aluminium Al. 27 | Silicon Si. 28 | Phosphorus P. 31 | Sulphur S. 32 | Chlorine Cl. 35·4 | | | | |
| 4. Long | Potassium K. 39 | Calcium Ca. 40 | Scandium Sc. 44 | Titanium Ti. 48 | Vanadium V. 51 | Chromium Cr. 52 | Manganese Mn. 55 | Iron Fe. 56 | Nickel Ni. 59 | Cobalt Co. 59 | Copper Cu. 63 |
| 5. Short | | Zinc Zn. 65 | Gallium Ga. 69 | Germanium Ge. 72 | Arsenic As. 75 | Selenium Se. 79 | Bromine Br. 80 | | | | |
| 6. Long | Rubidium Rb. 85 | Strontium Sr. 87 | Yttrium Y. 89 | Zirconium Zr. 90 | Niobium Nb. 94 | Molybdenum Mo. 96 | — | Ruthenium Ru. 104. | Rhodium Rh. 104 | Palladium Pd. 106 | Silver Ag. 108 |
| 7. Short | | Cadmium Cd. 112 | Indium In. 114 | Tin Sn. 118 | Antimony Sb. 120 | Tellurium Te. 126? | Iodine I. 127 | | | | |
| 8. Long | Cæsium Co. 133 | Barium Ba 137 | Lathanum La. 139 | Cerium Ce. 141 | Didymium Di. 147 | | | | | | |
| | | | | | Tantalum Ta. 182 | Tungstan W. 184 | — | Osmium Os. 199 | Iridium Ir. 193 | Platinum Pt. 195 | Gold Au. 197 |
| 9. Short | | Mercury Hg. 200 | Thallium Tl. 204 | Lead Pl. 207 | Bismuth Bi. 210 | | | | | | |
| 10. Long | — | — | — | — | — | — | Thorium Th. 234 | — | Uranium U. 239 | — | — |
| | $RCl$ $R_2O$ | $RCl_2$ $R_2O_2$ | $RCl_3$ $R_2O_3$ | $RCl_4$ $R_2O_4$ $RH_4$ | $RCl_5$ $R_2O_5$ $RH_3$ | $RCl_6$ $R_2O_6$ $RH_2$ | $R_2O_7$ $RH$ | $R_2O_8$ | | | |

with one atom of hydrogen to form the acids HF, HCl, HBr and HI. In Group VI. oxygen, sulphur, selenium and tellurium are dyads with respect to hydrogen, and unite with it to form the acids $H_2O$ (water), $SH_2$, $SeH_2$ and $TeH_2$. In Group V. nitrogen, phosphorus, arsenic, and antimony are triads with respect to hydrogen, and form the alkaline compounds $NH_3$ (ammonia), $PH_3$ (phosphine), $AsH_3$, and $SbH_3$. In Group IV. carbon and silicon are tetradic, and form $CH_4$ (methane) and $SiH_4$. In Group III. boron only forms a tri-hydride, $BH_3$, but this compound has not been obtained free from excess of hydrogen, and in this respect is similar to antimony in Group V. Bismuth does not form a tri-hydride, and the remainder of the known elements of the short series No. 9 are metallic.

The metals, with unimportant exceptions, such as copper forming cupric hydride ($CuH_2$) and platinum, which occludes hydrogen, do not combine with hydrogen, but they all combine with chlorine and oxygen, and may be supposed to be derived from HCl and $H_2O$ by replacement of the hydrogen, so that chlorine is a monad and oxygen a dyad with respect to combination with a metal, just as they are with respect to combination with hydrogen, thus:

| | | | | | |
|---|---|---|---|---|---|
| From | HCl | are derived | monochlorides | like | KCl |
| „ | $H_2Cl_2$ | „ | dichlorides | „ | $BaCl_2$ |
| „ | $H_3Cl_4$ | „ | trichlorides | „ | $AuCl_3$ |
| „ | $H_4Cl_4$ | „ | tetrachlorides | „ | $SnCl_4$, &c. |

As the molecule of water contains two hydrogen atoms, one-half or the whole of the hydrogen may be replaced, the product being a hydroxide in the first case and in the second an anhydrous metallic oxide, thus:

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| Type. | | Hydroxides. | | Oxides. |
|---|---|---|---|---|
| $H_2O$ | ... | KHO | ... | $K_2O.BaO$ |
| $H_4O_2$ | ... | $BaH_2O_2$ | ... | $SnO_2$ |
| $H_6O_3$ | ... | $AsH_3O_3$<br>$SbH_3O_3$<br>$BiH_3O_3$ | ...<br>... | $Sb_2O_3$<br>$WO_3$ |
| $H_8O_4$ | | $ZrH_4O_4$ | | |
| $H_{10}O_5$ | ... | | ... | $Sb_2O_5$ |

The hydroxides may also be regarded as hydrates—that is, a compound of an anhydrous oxide with water, thus:

| | | | |
|---|---|---|---|
| Barium hydroxide or hydrate | | | $BaH_2O_2 = BaO, H_2O$ |
| Stannic | „ | „ | $SnH_2O_3 = SnO_2, H_2O$ |
| Zirconium | „ | „ | $ZrH_4O_4 = ZrO_2, 2H_2O$ |
| Potassium | „ | „ | $2KHO = K_2O, H_2O$ |
| Bismuth | „ | „ | $2BiHO_2 = Bi_2O_3, H_2O$ |

A theoretical objection may be taken to the hydrate of a metal of uneven valency like potassium and bismuth as the molecule has to be doubled; but it will be shown later, by comparing the molecular volume of potassium hydroxide and sulphuric acid, that this objection is not valid.

The acidic elements also combine with chlorine and oxygen but, with the exception of carbon and silicon in Group IV., their valency is greater than it is in the hydrides.

Again, referring to the table, the elements of Group I. are all monads and form mono-chlorides, as NaCl (common salt); those of Group II. are dyads and form dichlorides, as $ZnCl_2$, or mon-oxides, as ZnO, one atom of oxygen as a dyad being equivalent to two atoms of chlorine; Group III. are triads and form tri-chlorides, as $AlCl_3$, or sesqui-oxides as $Al_2O_3$; Group IV. are tetrads and form tetra-chlorides, as $SnCl_4$ or di-oxides as $CO_2$; Group V. form penta-chlorides, as $PCl_5$, while the highest, or per-oxide, may be represented by $P_2O_5$ and $N_2O_5$; Group VI. form tri-oxides, as $SO_3$; and tungsten (or wolfram) forms a hexa-chloride, $WCl_6$.

No binary compound with more than six atoms of chlorine has been distinctly made out, so the analogy should not be pursued to the seventh and eighth group, although in certain compounds some elements of Group VII. appear to act as septavalent elements, as chlorine in perchloric acid, $HClO_4$, and manganese in permanganate of potash, $KMnO_4$; and in Group VIII. osmium and ruthenium form tetra-oxides, as $OsO_4$.

Elements vary from their maximum valency usually by two units; and those with an even valency are distinguished as "artiads," while those with an odd valency are "perissads." Tin, for instance, forms a tetra-chloride, $SnCl_4$, and also a di-chloride, $SnCl_2$; sulphur forms a tri-oxide, $SO_3$, and also a di-oxide, $SO_2$—in the one case it acts as a hexad and in the other as a tetrad with respect to the dyad oxygen.

The analogies exhibited by the table are by no means perfect. Oxygen, for instance, which should be a hexad, like sulphur, is (with few exceptions, as $Ag_4O$, $Pd_2O$, &c.) always a dyad; and the alkali metals of Group I. form compounds such as $KO_2$, $K_2O_2$, and $K_2O_4$, although these may be accounted for by the fact that a dyad element, such as oxygen, may add itself on to a compound without disturbing the total equivalence; but then it should also form $K_2O_3$, which compound, although formed under special conditions, is by no means stable. $K_2O$ is now considered a doubtful compound. The combination of a dyad, such as calcium, with a triad, such as phosphorus, should theoretically produce the compound $Ca_3P_2$, but no such combination is known. Calcium phosphide (CaP) contains equal atomic proportions of its elements.

The successive increments of weight naturally give rise to the idea of a simple primordial material, from which the so-called elements are formed, and it will be shown that, if the atom of that primordial material is assumed to be a tetrahedron one-half the weight of a hydrogen atom, it will suffice, if built up symmetrically, to form the whole of the seventy known elements with recurring shapes corresponding

with the vertical columns of the preceding table, just so far as the elements themselves correspond, and accounting for their combining capacities with each other, and for their metallic or acidic characteristics. The nearest whole number of the atomic weights as experimentally determined will be practically adhered to, but a small variation will in some cases be unavoidable. Cadmium will be taken as 110 instead of 112; iodine 125 instead of 127; didymium, determined by different experimentors as 142 and 147 respectively, will be fixed at 145; and several similar minor variations will unhesitatingly be made, as the atomic weights of all the elements, especially the heavier ones, cannot be considered as finally determined. In no case, with the possible exception of hydrogen, will the tetrahedra forming the different atoms be exactly regular, but the variations from the regular tetrahedron (that is, one with all its edges equal) are slight. The distortion increases with the larger elements, and eventually brings them to a natural termination in an unknown element slightly heavier than uranium.

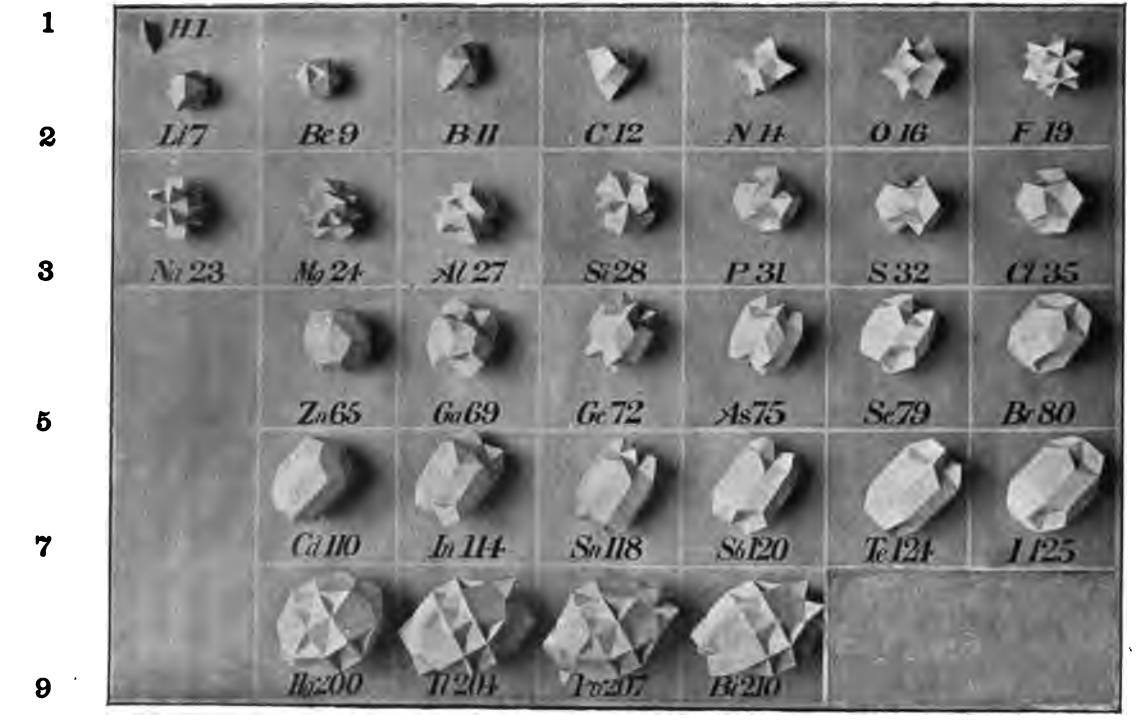
The atom of the primordial material being a tetrahedron, Fig. 1 will represent hydrogen formed from two of these placed base to base. Plate II. is a photograph of models of the atoms representing the whole of the short series of the table (page 15), each atom having two tetrahedra arranged symmetrically for every unit of atomic weight. Fluorine (No. 19) may be conceived as formed from twenty hydrogen atoms meeting radially in the centre but with two opposite tetrahedra cut off and thereby reducing the weight from 20 to 19. The twenty external points of this completed element form the outline of a pentagonal dodecahedron and by adding thirty more tetrahedra, the thirty edges of such a solid are formed (as shown by No. 35, which is the atom of chlorine), but whose twelve faces are sunk like an inverse pentagonal pyramid (Fig. 2 and Plate I.). These sunk faces, more or less developed, are characteristic of the acidic elements. By adding sixty more tetrahedra the inverse

pyramidal faces are converted into projecting pyramidal faces and the atom of zinc is obtained in No. 65. These projecting pyramidal faces more or less complete are characteristic of the metallic elements. It will be noticed that the number of each figure in this plate corresponds to the atomic weight of the atom represented. Any two contiguous projecting pyramidal faces of zinc (65) form two facets out of the five of another possible inverse pyramidal face, and ten of these faces may be completed and two others formed by adding fifteen tetahedra at opposite poles, as shown by bromine (No. 80), which has twelve inverse pyramidal faces exactly like chlorine, but also a girdle-belt of twenty facets in addition. The building up of bromine from zinc will be distinctly seen by Nos. 65, 69, 72, 75, 79, and 80. No. 110 shows cadmium formed by again adding sixty tetrahedra to the sunk faces of bromine, exactly as zinc was formed from the sunk face of chlorine; and No. 125 shows iodine formed from cadmium by again adding fifteen tetrahedra at each of the two poles, exactly as bromine was formed from zinc, and distinctly shown by Nos. 110, 114, 118, 120, 124, and 125. Iodine (125) has a girdle-belt of forty facets, and the next extra long series of metals, which include many rare elements, is formed partly by additions to this girdle-belt, and finally produces mercury, No. 200, from exactly 400 tetahedra with ten of the twelve projecting faces partly overlapped by the girdle-belt. The only known elements of this last short series are distinctly shown by Nos. 200, 204, 207, and 210.

It can now be seen that fluorine, chlorine, bromine, and iodine, each the end of a short series and exceedingly similar in their chemical properties, are also very similar in shape. Fluorine, bromine, and iodine, form fluorides, bromides, and iodides, exactly analogous to the chlorides. Immediately more tetrahedra are added to either of these a sudden and striking alteration in chemical behaviour of the element is noticed as the light metallic elements—sodium, potassium, rubidium and cæsium—are thus formed. Potassium, rubidium,

# PLATE II

THE FIVE SHORT SERIES SHOWING THE TRANSITION FROM METALLIC TO ACIDIC CHARACTERISTICS.



and cæsium commence the three long series of metals ending respectively in copper, silver, and gold, but the metallic properties are extended beyond these into the next short series again, and disappear only with the fresh formation of the sunk faces, more or less complete, of the acidic elements. As the size and weight of the elements increase the twelve sunk faces less and less obliterate the metallic properties until in the short series No. 9, mercury, thallium, lead, and bismuth are all metallic, and even in the short series Nos. 5 and 7, selenium and tellurium have certain metallic characteristics due to their girdle-belts, and thereby differ from oxygen and sulphur of the short series No. 2 and 3.

Plate II. contains the whole of the acidic elements, and by examining more particularly each of the short series here illustrated, the gradual transitions from the metallic to the acidic elements can be distinctly traced. Typical elements may now be studied of each group as represented by the vertical columns with their principal chemical compounds; and as the whole of the remaining elements are metallic they can be afterwards considered in a separate chapter on metals.

## SERIES 1.

### HYDROGEN.

Hydrogen is shown by Fig. 1 (and Plate I.) to have six triangular facets. Its properties are possibly due somewhat to its shape but more particularly to its smallness of bulk and weight in comparison with the other elements, and also to its higher relative velocity in comparison with the atoms of other gases.

Hydrogen unites in definite proportion to form binary compounds with all the elements which are decidedly acidic; and it is also an essential constituent of all the acids. Each hydrogen atom may be conceived as being in rapid vibration and effectually occupying a certain space within any acid, the

said space being entirely surrounded by the remaining acidic elements characterised by sunk faces. A metal is capable of displacing it entirely and occupying the same or a similar position.

## SERIES 2.

**Lithium** (No. 7, Plate II.) is shown to be an incomplete icosahedron formed from fourteen tetrahedra. The completed figure would, of course, have twenty triangular facets, but in this atom six are omitted in three pairs forming three sinkings as shown. It is the lightest solid known, and its chemical properties are, like most of the metals, principally passive chemical combination being due chiefly to the active acidic elements. It is very oxidisable.

**Beryllium** (or glucinium) (No. 9) has two tetrahedra on opposite sides omitted from the complete icosahedron. This atom has the pentagonal pyramidal faces so characteristic of the metals well developed. It is a white metal and can be forged and rolled into sheets, like gold.

**Boron** (No. 11) has two projecting tetrahedra on opposite sides. These projecting tetrahedra commence the formation of the sunk faces of the acidic elements, which in the succeeding atoms completely neutralise the metallic properties. Boron is only slightly acidic as it forms boric acid $B(OH)_3$ which turns litmus test-paper only to a wine-red colour; and it also forms the hydride $BH_3$, but this last has not been obtained free from excess of hydrogen. It forms binary compounds with the other acidic elements, just as a trivalent metal would do, as $BCl_3$, $B_2O_3$, BN.

**Carbon, Nitrogen, and Oxygen.**—Nos. 12, 14, and 16 (Plates I. and II.) show carbon, nitrogen, and oxygen, formed from twenty-four, twenty-eight, and thirty-two tetrahedra respectively, twenty of which form the complete icosahedron; and the remaining four, eight, or twelve are attached to the same number of facets, leaving sixteen, twelve, or eight facets, as the case may be, uncovered. These numbers, 16, 12, and 8, are equal to four times the number of

hydrogen atoms with which carbon, nitrogen, and oxygen respectively are capable of combining; and in the chapter on Chemical Compounds it will be shown how to arrange these atoms so that every hydrogen atom shall be enclosed by four of these facets in the compounds $CH_4$, $NH_3$, and $H_2O$. It is remarkable that out of the seventy differently shaped atoms there should be these three of the exact atomic weights 12, 14, and 16, with such a perfect relationship, corresponding to the three elements carbon, nitrogen, and oxygen, which, together with hydrogen, form such an enormous number of compounds that they are necessarily treated separately under the heading of Organic Chemistry: these numerous compounds will be reserved for a separate chapter. The peculiar relationship may also be seen by examining any pentagonal pyramidal face of the icosahedron (and there are twelve possible ones overlapping) in which there are four, three, and two facets vacant on carbon, nitrogen, and oxygen respectively, corresponding to their several combining capacities with hydrogen.

**Fluorine** (No. 19, Plate II.) has all the facets of the icosahedron covered, except two on opposite sides. Herbert Spencer has suggested that the atoms have been formed by a process of "The Survival of the Fittest," and it may be supposed that the incomplete figure has succeeded in displacing the more perfect one. At the extremely low temperatures now obtainable all chemical action ceases with this one exception that fluorine has such a strong affinity for hydrogen that it will even then unite with it. The vacant facets referred to are similar to those which cause oxygen to unite with hydrogen and although it is not necessary (as will be seen later) to have them vacant, still it is possible that they may assist in the formation of hydro-fluoric acid (HF) at an extremely low temperature. Gaseous fluorine is the most active element known, and this may possibly be accounted for by the large number of points which it presents to any substance it attacks, it being remembered that it

is always in an energetic state of vibration to enable its atom to fill a gaseous volume. Oxygen comes next in point of activity and it also comes next with its number of projecting points; but nitrogen with only eight points is relatively inactive, possibly because it has six faces (roughly like a cube) which it can present, instead of the eight points or corners. It will also be found that the light metals, such as sodium, potassium, rubidium, calcium, and strontium, are also characterised by points and are more active than the other metals in their combination with the acidic elements such as fluorine, chlorine, oxygen, and sulphur.

## SERIES 3.

### SODIUM, MAGNESIUM, ALUMINIUM, SILICON, PHOSPHORUS, SULPHUR, AND CHLORINE.

This series lies between the completed figure of fluorine with its atomic weight increased to 20 and chlorine already described which has thirty additional tetahedra forming the edges of a pentagonal dodecahedron. The metals sodium, magnesium, and aluminium of atomic weights $20+3$, $20+4$, and $20+(4+3)$ are formed by adding six, eight, and fourteen tetrahedra to the No. 20 atom; while the acidic elements, sulphur, phosphorus, and silicon, of atomic weights $35-3$, $35-4$, and $35-(4+3)$ are formed by omitting the same six, eight, and fourteen tetrahedra from the chlorine atom. The series is shown in Plate II. by Nos. 23, 24, 27, 28, 31, 32, and 35. The six tetrahedra added for sodium and omitted in sulphur correspond to the centre of the six faces of an escribed cube, while the eight tetrahedra added for magnesium and omitted in phosphorus, roughly correspond to the corners of a rectangular prism whose faces are parallel to the escribed cube. The same six and eight tetrahedra make the fourteen added or omitted in the one atom to form aluminium or silicon. It will be indicated in the chapter on Chemical Compounds how the

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position of these six and eight tetrahedra accounts for the combining capacities of each atom; but it will be instructive to compare sulphur with oxygen (Plate I.), two elements which are remarkable for forming many equivalent compounds. The six tetrahedra omitted in sulphur thereby exhibit two facets each on that atom; and these same six pairs of facets are also exhibited by the oxygen atom.

## SERIES 5.

### ZINC, GALLIUM, GERMANIUM, ARSENIC, SELENIUM, AND BROMINE.

This is the next short series following after a long series of metals, and here the formation of the sunk faces characteristic of the acidic elements can be clearly traced with the gradual elimination of the metallic characteristics. Zinc (No. 65) is a typical metal. The rare elements gallium and germanium (Nos. 69 and 72) are still metallic; in fact gallium is very much like mercury as it liquefies easily and adheres to glass, forming a mirror whiter than that produced by mercury. Arsenic, selenium, and bromine (Nos. 75, 79, and 80) have the twelve sunk faces more or less complete, and are decidedly acidic, as they unite in definite proportions with hydrogen to form the compounds $AsH_3$, $SeH_2$, and HBr—like phosphorus, sulphur, and chlorine; or nitrogen, oxygen, and fluorine. Germanium does not form a tetrahydride like silicon and carbon do; yet its oxide unites both with metallic oxides and also with acidic oxides; it illustrates the fact that as the size of the atoms increases the characteristic sunk faces of the acidic elements less and less obliterate the metallic properties.

## SERIES 7 AND 9.

### CADMIUM, INDIUM, TIN, ANTIMONY, TELLURIUM, AND IODINE.

### MERCURY, THALLIUM, LEAD, AND BISMUTH.

Cadmium holds a position in the table exactly analogous to zinc and mercury, and to correspond with this position it must be formed by adding sixty tetrahedra to the twelve sunk faces of bromine; consequently its atomic weight is (80+30), or 110 instead of 112—the number determined by experiment. Iodine is analogous to bromine and must be formed by adding thirty tetrahedra to cadmium, exactly as bromine was formed from zinc, and therefore its atomic weight must be (110+15) or 125. The atomic weight of tellurium, being somewhat doubtful, must be placed at 124, and tin at 117 instead of 118. These trifling alterations, with the exception of tin, are inevitable; and the series cadmium to iodine (Nos. 110, 114, 117, 120, 124, and 125) becomes exactly analogous to the series zinc to bromine. The relative density of vapour of iodine is usually given as 125·8, while theoretically it should be 127, to correspond with the observed atomic weight. In this series antimony is usually classed as a metalloid. Antimony combines with hydrogen, presumably to form $SbH_3$; but this compound has not been obtained free from excess of hydrogen. It is analogous in this respect to boron in Group III., Series 2, and it is interesting to trace the gradual predominance of the metallic characteristics as the size of the elements increases in the whole of the short series 2, 3, 5, 7, and 9. Tellurium and iodine are the only members of Series 7 that are decidedly acidic; but tin is acidic in its oxide $SnO_2$. Tellurium and iodine unite with hydrogen to form the compounds $TeH_2$ and HI,

but hydriodic acid is easily resolved into its elements by heat.

Series 9 has no elements corresponding to tellurium and iodine yet discovered, and mercury, thallium, lead, and bismuth, which constitute the series 200, 204, 207, and 210, are all metallic. Bismuth does not form a trihydride $BiH_3$, like antimony and arsenic.

## CHAPTER IV.

### CHEMICAL COMBINATION.

It was proved by means of specific heat (Chapter II.) that every atom (whether of an element or simple compound) occupies its own atomic volume by virtue of its own kinetic energy; so that to obtain the exact spacial arrangement of

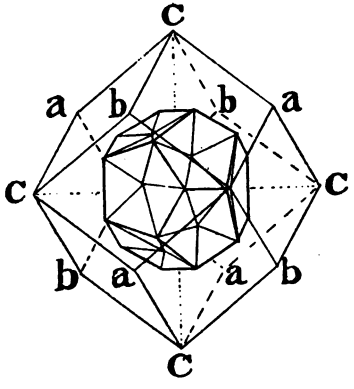


Fig. 2.

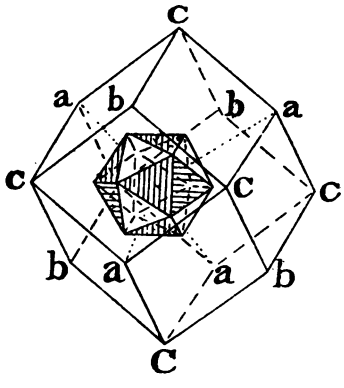


Fig. 3.

the atoms in a known compound is purely a problem of symmetrical geometrical arrangement. The typical hydrogen compounds HCl, $H_2O$, $NH_3$, and $CH_4$ of the typical elements carbon, nitrogen, oxygen, and chlorine, are the best to select for the purpose. A rhombic dodecahedron has interfacial angles of 120° and 90° respectively, so that a number of them with coincident faces will exactly fill space. Figs. 2, 3, 4, and 5 show each of the typical atoms inscribed in such a solid, so that if these atoms are arranged in space dodecahe-

drally, the character of the interspaces so formed may be clearly described. The projecting tetrahedra of each atom are omitted, and their positions indicated by the hatched facets of the icosahedron.

There are eight corners on the dodecahedron (four lettered *a* and four lettered *b* respectively), where four solids (or three faces of one solid) meet, and these corners coincide with the radius of eight sunk facets of oxygen (Fig. 3); so that if an atom of hydrogen is placed at each of these points, every one

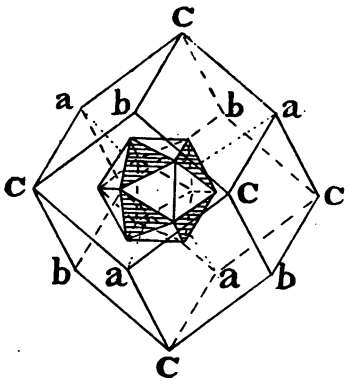


FIG. 4.

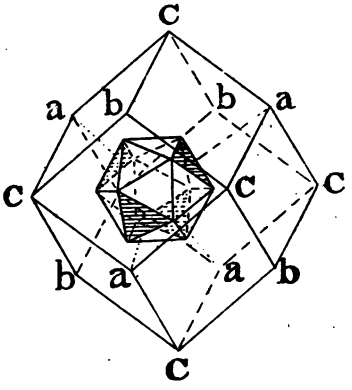


FIG. 5.

will be enclosed by four different atoms of oxygen; and, as every oxygen atom touches eight hydrogen atoms, there must be twice the number of hydrogen atoms; and a perfect mechanical and geometrical arrangement corresponding to the atoms of water ($H_2O$) is obtained. The necessity of symmetrical build in every atom is at once apparent; and hydrogen, being a monad and represented in structural formulæ with a single bond, while oxygen, being a dyad, is represented with two bonds, it can be at once noted (at least in this one example) in what the bonds really consist. Each hydrogen atom has the kinetic energy of four radially equidistant oxygen atoms playing upon it to keep it in position and corresponding to the single bond, while every oxygen

atom has, similarly, the kinetic energy of eight radially equidistant hydrogen atoms playing upon it and corresponding to the double bond. Any unsymmetrical deviation from the radial equidistance would cause a deviation in the position of the surrounded atom, and produce chemical change. This arrangement must correspond with water in the liquid and solid conditions, as no closer arrangement of the oxygen atoms seems possible; but a different arrangement corresponding to the gaseous condition is possible.

Imagine a space occupied with super-heated steam to be divided by parallel planes into infinitely small cubes with an atom of oxygen in each of the corners where eight cubes meet, so that the eight sunk facets of oxygen will face eight different cubes. The interspaces thus formed at the centre of the cubes may be supposed to contain two atoms of hydrogen in rapid vibration, but always moving parallel to each other with the velocity reduced; so that twice their total kinetic energy being equal to their combined mass multiplied by the square of their common velocity, the two atoms act as one so far as the temperature and pressure and specific heat of the gas or steam is concerned. The compound will then only occupy two gaseous volumes, and accord with the table on page 5. By heating to a still higher temperature the atoms of hydrogen finally escape even from this amount of confinement, and "dissociation" results.

The phenomenon of dissociation of gases, and also of vaporisation of liquids or solids, is evidently quite consistent with the assumed conditions. In both cases the dissociation or vaporisation will go on until the resulting gas or vapour reaches a certain pressure corresponding to a particular temperature, and any increase or decrease of the amount of heat or of the pressure will cause a corresponding increase or decrease, as the case may be, in the relative amount of the gas dissociated, or of the liquid or solid vaporised.

Fig. 2 shows the chlorine atom with an escribed rhombic dodecahedron. It will be remembered that this escribed solid

will exactly fill space; but it should also be noted that it is a mean shape of all the different atoms, and just as they advance or recede from this mean shape by added or omitted tetrahedra, so is their valency or combining capacity increased.

The outline of the chlorine atom is a pentagonal dodecahedron, which can be seen to vary from the escribed rhomboidal one at the six equi-radial points C, where four faces of the latter meet; and if an atom of hydrogen is placed at each of these six points each one will touch or be enclosed by six different atoms of chlorine, and the liquid hydrochloric acid may be thus delineated, but it must be remembered that this compound cannot, at ordinary temperature and pressure, be obtained as a liquid free from combined water. Sodium will be found peculiarly fitted by its shape to occupy these six positions to form sodium chloride. The single bond of a monad element in this case appears to be due to the kinetic energy of six radially equi-distant atoms playing upon it to keep it in position. Gaseous hydrochloric acid must be a cubic arrangement similar to that described for super-heated steam, with each hydrogen atom occupying an equal volume with each chlorine atom. A plane section of the formation may be imagined like the squares of a chess board (Fig. 16), the black squares or cubes being the positions, say, of the chlorine atoms, and the white of the hydrogen atoms.

Fig. 4 shows the nitrogen atom with an escribed rhombic dodecahedron to be just the reverse of the oxygen atom, as it has eight projecting tetrahedra in the same place as the sunk facets of oxygen, so that these actual positions become untenable for hydrogen; but the three facets of each of these eight tetrahedra become accessory to the adjacent three facets on the icosahedron at the base. There are twelve such exposed facets on the icosahedron, and each atom of hydrogen in ammonia ($NH_3$) may be more or less confined in position by one such facet on each of four different nitrogen atoms; and the motions of the hydrogen atoms must be such that every three of them pass through the eight points previously

referred to, and are guided to the facets at the base by the projecting tetrahedra. The hydrogen atoms are evidently nomadic, their motions not being so confined as in the neutral compound, $H_2O$ (water), or the typical acidic compound, HCl (hydrochloric acid), already described. Ammonia is a beautifully balanced piece of mechanism, in which the nitrogen is kept in position by the kinetic energy of twelve radially equidistant atoms of hydrogen, corresponding to a triple bond; and this is evidently the gaseous arrangement of two volumes, the hydrogen moving in triplets.

As the outline of the nitrogen atoms are roughly like a cube, it is evident that, if they are arranged cubically, with one atom of hydrogen between every *two* opposite faces, the compound would still be $NH_3$, as there are six such faces to each nitrogen atom; but (as is the case with anhydrous ammonia in the liquid form) this arrangement is unstable, and should only be obtainable by the application of cold and pressure.

There are many things to be learned from the successful representation of ammonia. It has indicated the first real distinction between the basic and acidic hydrides to be that in the former case the hydrogen atoms are nomadic and in the latter, as in hydrochloric acid, each atom occupies a confined space, from which it may perhaps be displaced by a metal. Some similar distinction may be anticipated in the basic and acidic oxides. This nomadic hydrogen may be the cause of the peculiar toughness of the solid ammonium chloride and of the nitrogenous organic compounds, and may, perhaps, also help to unravel the mystery of the great toughness of the pure metals. It will also serve to indicate that the prevalent conception of molecules may be true to this extent, that at any atomic instant every atom of nitrogen may be in actual collision with three atoms of hydrogen, but in the next movement the nitrogen atoms may be each in collision with other three atoms of hydrogen; so that there may be, perhaps, four different positions where each nitrogen atom is continually forming a molecule in which the identical hydro-

gen atoms are always changing. The nomadic hydrogen atoms no doubt impart a certain amount of toughness or stability to the smoke-rings of ammonia chloride formed by Professor Tait's apparatus; and the tenacity of the films of soap-bubbles may likewise be due to alkalinity.

The carbon atom (Fig. 5) has four radially equi-distant projecting tetrahedra which point to the corners *a* of the escribed dodecahedron, whose four similar remaining corners, *b*, are each exactly over a blank facet of the icosahedron, and each of these latter may be occupied by an atom of hydrogen. There are altogether sixteen exposed facets of the icosahedron, each of which may collide with an atom of hydrogen; and, as each atom of hydrogen is enclosed by one facet on each of four different atoms of carbon, the formation of the atoms in the compound $CH_4$ (methane) is obtained. The four facets enclosing any one atom of hydrogen include one of the four central facets *b* just referred to, but the other three are each at the base of a projecting tetrahedron on the three contiguous carbon atoms. A remarkable peculiarity of this formation is that the carbon atom is itself approximately a tetrahedron; the space occupied by a set of four atoms of hydrogen, and enclosed by four contiguous atoms of carbon is also approximately a tetrahedron; and likewise the space occupied by every individual atom of hydrogen, as each and all are enclosed by four faces or facets more or less equally inclined. The carbon compounds are further described in the separate chapter on Organic Chemistry.

The symmetrical formation described for the typical hydrogen compounds is the same in all binary hydrides. Thus:

| | | |
|---|---|---|
| HCl | = HF, HBr, HI | (1) |
| $H_2O$ | = $SH_2$, $SeH_2$, $TeH_2$ | (2) |
| $NH_3$ | = $PH_3$, $AsH_3$, $SbH_3$ ($BH_3$) | (3) |
| $CH_4$ | = $SiH_4$ | (4) |

In the monad group, (1), the shapes of the halogen atoms are very similar, each having twelve identical faces.

In the dyad group, (2), sulphur is remarkably like oxygen; in fact six equi-radial pairs of facets (each pair forming a bird's mouth) are identical on each atom (see Plate I.).

In the third group the triad atoms are not at all similar, but there will be found twelve symmetrical points on each.

In the fourth group silicon is the only element to form a tetrahydride besides carbon.

In Groups 1 and 2 one or more atoms of the hydrogen may be replaced by a metal, but in Groups 4 and 3 the hydrogen is replaceable by an acidic element, like chlorine, and it is at once evident that the formation of a large series of compounds is at once obtainable from the known formation of the hydrides.

It should be noted that the binary compounds are really formed by means of the interspaces due to the more or less inverse faces of the acidic elements, and the metallic element, having more or less projecting faces, is capable of occupying one or more of these interspaces. The more dissimilar in this respect the two elements, the more energetically they combine and the more stable the product. Hitherto it has not been possible to show such exact distinction between acidic and basylous (or metallic) elements, as they only show their true characteristics in combination with other elements. Ammonia, for instance, is intensely alkaline; it restores the colour to blue litmus paper which has been reddened by an acid, and also turns turmeric paper brown; while hydrochloric acid reddens blue litmus paper, and is intensely acid. These two compounds combine and form a neutral salt.

The characteristics of the binary hydrides are strangely typical of that large and important class of compounds, the oxides. The anhydrous oxides do not show any acidic or basylous characteristics, except in some cases the capability of the one to combine with the other. It is only by combination with one or more molecules of water that the acidic or basic

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properties are developed, and then the base combines with the acid to form salts by replacing the hydrogen of the combined water, just like the binary hydrides. The formation is evidently similar, but more complex; but the acidic and basic characteristics are somewhat reversed. The polyhydrides are basic, but the polyoxides are acidic; and the lower hydrides are acidic, while the lower oxides are basic, as follows:

$$\begin{aligned} NH_3 + HCl &= NH_4Cl \\ NH_3 + HNO_3 &= NH_4NO_3 \\ Na + HCl &= NaCl + H \end{aligned}$$

$$\begin{aligned} (H_2O)SO_3 + K_2O &= K_2SO_4 + H_2O \\ (H_2O)SO_3 + ZnO &= ZnSO_4 + H_2O \\ (H_2O)N_2O_5 + Na_2O &= 2NaNO_3 + H_2O \end{aligned}$$

The basic tri-hydride $NH_3$ is arranged in the same column with the acidic oxides $SO_3$, $N_2O_5$; and the acidic mono-hydride HCl in the same column with the basic oxides $K_2O$, ZnO, and $Na_2O$. Ammonia nitrate $NH_4NO_3$, may be regarded as a stepping-stone from the hydrogen salt, $NH_4Cl$, to the oxygen salts, as $NaNO_3$ or $ZnSO_4$, for instance. This will indicate a method of forming oxides from the known formation of the hydrides, but it is not necessary to pursue it further at present, as the oxides may be more readily obtained from the one already known, namely $H_2O$.

In the atomic formation described for water *in the liquid condition* every hydrogen atom may be replaced by a monad metal, and the exact spacial arrangement of the atoms is thus obtained in the oxides $Li_2O$, $Na_2O$, $K_2O$, $Rb_2O$, $Cs_2O$, &c. (See periodic table, page 15.) With an hydroxide, as NaHO or KHO, one-half of the hydrogen only—that is to say the hydrogen at four instead of eight points—would be replaced. The alkalinity may be due to the nomadic hydrogen, as was the case with ammonia, if it can be supposed that the metal, simply by its inferior diffusive power (caused by the superior weight and relatively slower motion of its atom), is continu-

ally displacing a fresh atom of hydrogen, so that both the metal and hydrogen are in reality nomadic. The metal would be thus divided atomically and capable of at once displacing the hydrogen of any acid with which it is brought in contact.

In the atomic formation described for water *in the gaseous condition* every two hydrogen atoms may be replaced by a dyad metal, and the exact spacial arrangement of the atoms is thus obtained in the oxides BeO, MgO, CaO, ZnO, SrO, CdO, BaO, HgO, CuO, AgO, &c. (See periodic table, page 15.) It should not be difficult to represent a hydroxide such as $ZnH_2O_2$.

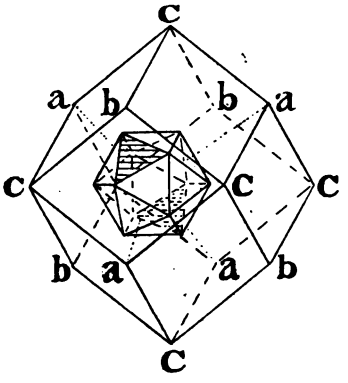


FIG. 6.

In a sesqui-oxide the oxygen must touch four different atoms of the metal, while the metal touches six different atoms of oxygen. Fig. 6 shows an atom of boron inscribed in a rhombic dodecahedron having six of the eight points where three faces or four solids meet available to receive an atom of oxygen. The other two are made untenable for oxygen by the projecting points of boron. In this case *two* sunk facets of one oxygen atom face one atom of the metal, and each metallic atom is surrounded by six such pairs of facets. The exact spacial arrangement of the atoms is thus obtained in the sesqui-oxides $B_2O_3$, $Al_2O_3$, $Sc_2O_3$, $Ga_2O_3$, $Y_2O_3$, $In_2O_3$, $La_2O_3$, $Fl_2O_3$, $Fe_2O_3$, &c. (See periodic table, page 15.)

Any binary compounds with a larger proportion of oxygen must obviously have some surplus sunk facets of the oxygen which do not face the other element of the compound. A different type of oxide is at once obtained just where acidic characteristics become pronounced. The sesqui-oxides are on

the border between the basylous and acidic oxides, and do not form nearly such strong bases for chemical union with the acidic oxides as the alkaline oxides $Na_2O$ or $K_2O$, for instance; or as the monoxides ZnO, CaO, &c.; and in some cases they may even act as acidic oxides towards the more basic ones.

The acidic oxides may be described with reference to carbon-dioxide ($CO_2$) and sulphur trioxide ($SO_3$). No element has so strong an affinity for oxygen as carbon at high temperatures; and it is noteworthy that the oxygen atom has a peculiar fitness for carbon, as the eight sunk facets corresponding to the solid angles *a*, *b*, (Fig. 3), are each surrounded by three facets of the adjacent projecting tetrahedra, and the eight faces thus formed exactly correspond to four similar but inverse faces on the carbon atom, each formed with four facets. Four contiguous atoms of oxygen thus completely envelop the sixteen exposed facets on the icosahedron of the carbon atom. Somewhat similarly sulphur has the next strongest affinity for oxygen, and in the compound $SO_3$ six contiguous atoms of oxygen fit on and completely envelop one sulphur atom, but in this case it is the oxygen atom sitting on the sulphur like a three-legged stool, with one leg, or projecting tetrahedra, of each oxygen atom in the six bird's mouths formed by the omitted tetrahedra, by virtue of which sulphur differs from the chlorine atom, and by which it also exactly corresponds to oxygen (see Plate I.). Therefore, as it was shown by means of specific heat that each atom occupies its own atomic volume, so that oxygen must occupy sensibly as much space as sulphur and carbon, and combines in the proportion of $SO_3$ and $CO_2$, it follows that because sulphur collides with six contiguous oxygen atoms, every oxygen atom can only collide with two contiguous atoms of sulphur, and because carbon collides with four contiguous oxygen atoms in this case also the oxygen atoms can only collide with two contiguous atoms of carbon. The proportion of oxygen in the former case is $6 \div 2$ and in the

latter 4 ÷ 2. It may be therefore safely inferred that in the representative acidic oxides $CO_2$, $SO_3$, and likewise $P_2O_5$, every oxygen atom can only collide with two atoms of the acidic element, so that these oxides must be characterised by empty acidic spaces, due to the disengaged sunk facets of oxygen, of which there are eight to each atom. As the acidic oxides contain not less than two atoms of oxygen to one of the acidic element, it follows that the whole of them, as $CO_2$, $SiO_2$, $SnO_2$; $N_2O_5$, $P_2O_5$, $As_2O_5$, $Sb_2O_5$, $Bi_2O_5$; $SO_2$, $SO_3$, $SeO_3$, $TeO_3$; $ClO_4$, &c. (see periodic table, page 15), must be characterised by these disengaged sunk facets, which, in the basic oxides previously described, are all in collision with the metal.

As was the case with the hydrides so, when the exact spacial formation of the oxides is known, the sulphides, selenides, &c., of Group VI. of the periodic table are known also.

The halogen elements of Group VII. also form binary compounds with the monad, dyad, triad and tetrad metals, as NaCl, $ZnCl_2$, $AlCl_3$, $SnCl_4$. These are exactly analogous to the hydrides ClH, $OH_2$, $NH_3$, $CH_4$, and practically complete the binary compounds.

The binary compounds, then, are all formed by the combination of an acidic element with a basylous or metallic element, the resulting compound being an acid, as HCl, or a salt, which may be derived from such an acid, as NaCl, or an alkali, as $NH_3$, which forms the basylous radical $NH_4$ in ammonium chloride, $NH_4Cl$; or the special compound $CH_4$, forming the foundation of the organic compounds, or a basic oxide or sulphide, &c., as $K_2O$, ZnO, ZnS, or an acidic oxide or sulphide, &c., as $SO_3$, $P_2O_5$, $As_2S_5$.

Just so far as a binary compound is acidic or basylous in character is it capable of further combination, the acidic compound uniting with the basic compound to form a salt (the acids being considered as hydrogen salts), just like the acidic and metallic elements were shown to do. Just as the

binary compounds were first obtained by means of the typical elements in the formation of typical compounds, so the atomic formation of the oxygen salts may be obtained by considering a typical acid $H_2SO_4$ (or $SO_3+H_2O$) and a typical base 2KHO (or $K_2O+H_2O$).

The oxygen acids are formed by the combination of an acidic oxide with water, and these oxides, as was the case with the acidic elements and hydrogen, do not show their acidic properties until so combined.

### *Comparison of the Molecular Volume of* $H_2SO_4$ *with that of* 2KHO.

Sulphuric acid can be obtained in the liquid condition free from excess of water. Similarly the basic oxide $K_2O$ unites with water to form the hydroxide KHO, and this characteristic alkali can be concentrated from solution by heat until the whole of the excess of water is driven off and a solid hydroxide, corresponding to the composition KHO, is formed of density 2·2.

| Compound. | Specific gravity. | | Molecular weight. | | Relative molecular volume. |
|---|---|---|---|---|---|
| $H_2SO_4$ . . | 1·842 | ÷ | 98 | = | ·0186 |
| KHO . . | 2·200 | ÷ | 56 | = | ·0393 |
| $K_2H_2O_2$ . . | 2·200 | ÷ | 112 | = | ·0196 |

As shown by the table, the relative molecular volume (obtained by dividing the observed specific gravity by the calculated molecular weight) clearly indicates that two volumes of liquid or solid KHO occupy roughly the same volume as one of $H_2SO_4$. It will be shown, when dealing with dibasic acids, that the $H_2$ of sulphuric acid acts as one atom so far as atomic volume is concerned. There are, therefore, six atomic volumes in $H_2SO_4$ as well as in 2KHO, and it would be expected from the reasoning of Chapter II. that these compounds would occupy sensibly the same volume. This comparison between compounds so opposed in pro-

perties is useful merely as a check on the theories now being advanced before proceeding to find the spacial arrangement of the constituent atoms. The atomic formation of potassium hydroxide has already been described, and it is clear there is nothing essentially different in the molecular formation of an acid beyond what is due to the shape and relative number of the constituent atoms.

Acids also differ from hydroxides by the fact that some are monobasic while others are dibasic, tribasic, or quadribasic, each containing one, two, three, or four atoms, as the case may be, of replaceably hydrogen, as shown by the following table :

*Monobasic Oxygen Acids.*

| | | | |
|---|---|---|---|
| Hyponitrous . . | $HNO$ | Hypochlorous . | $HClO$ |
| Nitrous . . . | $HNO_2$ | Chlorous . . . | $HClO_2$ |
| Nitric . . . . | $HNO_3$ | Chloric . . . | $HClO_3$ |
| Metaphosphoric . | $HPO_3$ | Perchloric . . . | $HClO_4$ |
| Metaboric . . . | $HBO_2$ | Bromic . . . . | $HBrO_3$ |
| Metantimonic . | $HSbO_3$ | Iodic . . . . | $HIO_3$ |

*Dibasic Oxygen Acids.*

| | | | |
|---|---|---|---|
| Sulphurous . . | $H_2SO_3$ | Selenious . . | $H_2SeO_3$ |
| Sulphuric . . . | $H_2SO_4$ | Selenic . . . | $H_2SeO_4$ |
| Pyrosulphuric . | $H_2S_2O_7$ | Tellurous . . | $H_2TeO_3$ |
| Thiosulphuric . | $H_2S_2O_3$ | Telluric . . . | $H_2TeO_4$ |
| Dithionic . . . | $H_2S_2O_6$ | Manganic . . | $H_2MnO_4$ |
| Trithionic . . . | $H_2S_3O_6$ | Chromic . . . | $H_2CrO_4$ |
| Tetrathionic . . | $H_2S_4O_6$ | Stannic . . . | $H_2SnO_3$ |
| Pentathionic . . | $H_2S_5O_6$ | Metasilicic . . | $H_2SiO_3$ |

*Tribasic Acids.*

| | | | |
|---|---|---|---|
| Orthophosphoric . | $H_3PO_4$ | Arsenic . . . | $H_3AsO_4$ |

*Quadribasic Acids.*

| | | | |
|---|---|---|---|
| Pyrophosphoric . | $H_4P_2O_7$ | Orthosilicic . . | $H_4SiO_4$ |

In a dibasic acid one-half of the hydrogen may be replaced thus:

$$K + H_2SO_4 = KHSO_4 + H,$$

and the remaining half may be replaced by a subsequent reaction thus:

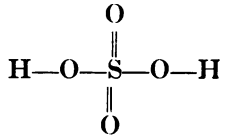
$$K + KHSO_4 = K_2SO_4 + H.$$

Similarly with a tribasic acid, one-third, two-thirds, or the whole of the hydrogen, may be finally replaced; and with a quadribasic acid the hydrogen is replaceable by fourth parts. There must be some peculiar spacial formation of the atoms to account for these phenomena.

The number of replaceable hydrogen atoms in an acid (whether mono-, di-, tri-, or quadri-basic) in most cases corresponds to the binary combining capacity with hydrogen of the polyvalent element forming the acidic oxide, such as that of sulphur in $H_2SO_4$, and if the gaseous arrangement of the atoms $SH_2$ is supposed to be also their relative arrangement in the acid, with the four oxygen atoms symmetrically interspaced, it will probably be the correct arrangement. Every pair of hydrogen atoms would then be enclosed by oxygen atoms, and one or both may be replaceable by a metal. The absolutely neutral compound (water) is capable of acting as an acidic oxide in combination with a basic oxide, as $K_2O$, $H_2O$; and as a basic oxide in combination with an acidic oxide, as $H_2O$, $SO_3$. These contradictory properties may perhaps be explained by considering the liquid form of water to be the basic oxide, and the gaseous form as the acidic oxide. It is also noteworthy that the nitrogen acids are monobasic, the oxygen atoms having evidently displaced the remaining two atoms of hydrogen of ammonia $NH_3$ and destroyed its akaline properties; but such is not the case with the phosphorus, arsenic, and antimony acids, as they each form tribasic acids $H_3PO_4$, $H_3AsO_4$ and $H_3SbO_4$, although they also form the monobasic acids $HPO_3$, $HSbO_3$ and $HAsO_3$. The slightest evidence that will indicate what is basic and what is acidic must be noted.

The view that the hydrogen of an acid in the liquid form is arranged as in the gaseous form of its binary compounds is supported by the fact that by volatilising acids other than monobasic the volume of the resulting vapour indicates that dissociation has occurred, as they mostly occupy four volumes. A monobasic acid, like $HNO_3$, probably has two of its molecules dissociated into $N_2O_5$ and $H_2O$, and the resulting gaseous volume is the same as with one molecule of sulphuric acid, $H_2SO_4$, for instance, which dissociates into $SO_3$ and $H_2O$. The hydr-acids, as HCl, $SH_2$, are only binary compounds and are gases at ordinary temperatures, and occupy the usual two volumes. It can be seen that if the replaceable hydrogen in a liquid oxygen acid is always arranged as in the binary compounds HCl, $H_2O$, $SH_2$, $PH_3$, or $CH_4$, with the additional oxygen atoms symmetrically interspaced, then those acids cannot be volatilised into gases without dissociation occurring.

As the majority of the acids cannot be obtained free from excess of water at ordinary temperatures it is more difficult to obtain their exact atomical formation, but that of the exceptional acid $H_2SO_4$ is free from this difficulty, and may be obtained by the help of its structural formulæ:



In these formulæ the connecting links indicate the equivalence; sulphur being a hexad is connected with the other elements by six such bonds, the dyad oxygen by two, and the monad hydrogen by one.

Imagine the squares of a chess board (Fig. 16) to represent cubes, the black ones occupied by the sulphur, and each white one by two atoms of hydrogen exactly as described for water or sulphuretted hydrogen in the gaseous condition. The oxygen atoms must be symmetrically disposed about the

corners or edges or faces of the cubes so that one half interpose themselves between the hydrogen atoms and the sulphur, and the other half between the sulphur atoms only. The first half may be disposed by placing an oxygen atom at all the corners so that four of the eight sunk facets face the cubes containing the sulphur and the other four facets similarly face the cubes containing the hydrogen atoms (Fig. 7) and the radical $H_2SO_2$ is obtained with all the satisfied bonds perfectly accounted for as in the structural formulæ:

$$\begin{array}{ccccccc} & & \| & & & & \\ H & — & O & — & S & — & O — H. \\ & & \| & & & & \end{array}$$

But this radical also forms a definite acid $H_2SO_2$ and the simpler radical $H_2O_2$ is common to all the dibasic acids and is the acidifying principle. The other atoms are simply accessory and give the special characteristics to the different oxygen acids.

The radical $H_2O_2$ can be divided in halves so that there is one hydrogen atom only in the acidic space held there by four radially equi-distant oxygen atoms at the alternate angles of the assumed cube; and this radical HO— is common to all the monobasic oxygen acids. Hypochlorous acid (HClO) for instance differs from hydrochloric acid (HCl) simply by the interposition of the oxygen, the hydrogen and the chlorine atoms being each held in position by four radially equi-distant oxygen atoms and the bonds are satisfied exactly as in the structural formulæ:

$$H—O—Cl.$$

The dividing of eight atoms at the angles of a cube into two sets of four as described, each set occupying alternate angles, can be best understood by comparing the shape of a carbon atom, which has four radially equi-distant points, with that of a nitrogen atom, which has eight (Plate I.). It will be seen that nitrogen can be formed by the symmetrical interpenetration of two carbon atoms.

The atomic formation of the hydroxyl radical HO and

$H_2O_2$ is possibly the only really definite structure in the acids as the arrangement of the remaining oxygen atoms appears necessarily to be somewhat nebulous as regards their individual bonds. These hydroxyl radicals also give the atomic formation of the metallic radicals as potassoxyl KO, zincoxyl $ZnO_2$, &c, in their several salts, as $KNO_3$, $K_2SO_4$, $ZnSO_4$, &c.

The locating of the remaining atoms of oxygen in the acids must be done systematically, and as it is of the first importance to lay down general principles only, it is not necessary to pursue this subject further. These crystalline structures presently described would be of assistance for this purpose. It seems probable that the cubicle formation described is the foundation for most simple salts, but it may become distorted by additional atoms. The cubicle formation may also become dodecahedral.

If Fig. 7 is a plane section of a dodecahedral arrangement each oxygen atom would collide with four instead of eight other atoms of sulphur and hydrogen combined; and the proportion of the whole of the atoms would be represented by the formulæ $H_2SO_4$. (Such a formation would not be possible with a simple halogen acid like HCl, as the hydrogen atom could not be surrounded on twelve sides by different chlorine atoms.) The polyvalency of sulphur would thereby be accounted for, as the hydrogen simply occupies the spaces provided and the structural formation of $H_2SO_4$ is primarily due to the sulphur atoms.

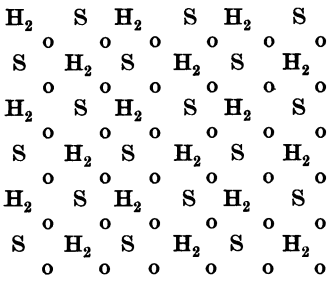


FIG. 7.

Similarly with the hydrogen salts as $NH_4Cl$ the structure of which may be as shown in the diagram (Fig. 8) supposing the arrangement to be dodecahedral. The analogous salt NaCl crystallises in cubes and likewise sodium nitrate shown

in the next diagram, Fig. 9, but in the latter case two-thirds of the oxygen take the cubic positions as shown between the two faces of sodium and nitrogen (corresponding to C Fig. 2, p. 30), forming a radical $NaNO_2$ (not the nitrite, as it contains no hydroxyl), and the other oxygen atom occupies the alternate angles as described with the monobasic acid radicle H—O—(hydroxyl).

These formations may not be correct ones but there is scarcely an alternative for any of them, and they are

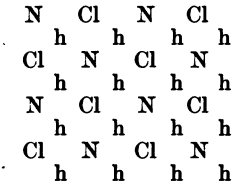


FIG. 8.

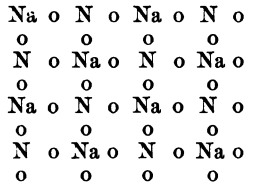


FIG. 9.

interesting as showing the probable connection between the halogen and oxygen salts.

The dodecahedral formation may be obtained by compressing every four layers of a cubic formation into two layers. Either of these arrangements may become distorted by additional atoms, and there is evidently a limit to the number of atoms that can be contained in two liquid volumes.

When the whole of the hydrogen in an oxygen acid is displaced by a metal, a normal oxygen salt results, and the number of molecules of acid oxide contained in one molecule of the salt is always equal to the number of oxygen atoms in the basic oxide. Thus:

$$K_2SO_4 = K_2O, SO_3$$
$$BaSO_4 = BaO, SO_3$$
$$Sn(SO_4)_2 = SnO_2\ 2SO_3$$
$$Al_2(SO_4)_3 = Al_2O_3, 3SO_3$$

With potassium sulphate, for instance, there is one atom of

oxygen in the base to one of the acidic radical $SO_3$. The relative position of the oxygen atoms in the basic oxides has already been described, and these should likewise indicate the relative positions of the acidic radicals in a solution of any salt, and also the relative position of each atom in a crystal of that salt. Stannic oxide, $SnO_2$, is really an acidic oxide and unites with water to form acids, but is itself basic towards a powerful acid like $H_2SO_4$.

## CHAPTER V.

### CRYSTALLINE STRUCTURE.

THAT there is a very considerable motion of the atoms, even in the solid state, is shown by the specific gravity of, say, the platinum group of metals 21·5, against that of the similar iron-nickel-cobalt-copper-zinc group, of which zinc is 7·1—a difference which would not be accounted for by their different atomic weights, supposing the atoms to be packed closely together.

*Specific Volumes of Metals* (Group VIII.).

| | Atomic weight. | | Specific density. | | Specific volume. |
|---|---|---|---|---|---|
| Iron . . . | 56 | ÷ | 7·80 | = | 7·2 |
| Nickel . . | 59 | ÷ | 8·60 | = | 6·9 |
| Cobalt . . | 59 | ÷ | 8·50 | = | 7·0 |
| Copper . . | 63 | ÷ | 8·95 | = | 7·0 |
| Zinc . . . | 65 | ÷ | 7·10 | = | 9·1 |
| Ruthenium . | 104 | ÷ | 11·40 | = | 9·1 |
| Rhodium . . | 104 | ÷ | 11·00 | = | 9·4 |
| Palladium . . | 106 | ÷ | 11·80 | = | 9·0 |
| Silver . . | 108 | ÷ | 10·50 | = | 10·3 |
| Cadmium . . | 110 | ÷ | 8·70 | = | 12·6 |
| Osmium . . | 194 | | | | |
| Iridium . . | 194 | ÷ | 21·80 | = | 8·9 |
| Platinum . . | 196 | ÷ | 21·50 | = | 9·1 |
| Gold . . | 198 | ÷ | 19·34 | = | 10·0 |
| Mercury (liquid) | 200 | ÷ | 14·80 | = | 13·5 |

*Specific Volumes of Acidic Elements* (Group VII.).

| | Atomic weight. | | Specific density. | | Specific volume. |
|---|---|---|---|---|---|
| Chlorine (liquid) | 35 | ÷ | 1·33 | = | 26·3 |
| Bromine (liquid) | 80 | ÷ | 3·19 | = | 25·1 |
| Iodine . . | 125 | ÷ | 4·95 | = | 25·2 |

For some reason, no doubt a result of the peculiar path of its atoms, the acidic elements of Group VII. occupy a much larger specific volume than the heavy metals of Group VIII. and the light metals of Group I., three of which, varying little in atomic weight and atomic shape from the three acidic elements of Group VII., occupy even a larger specific volume.

*Specific Volumes of Metals* (Group I.).

| | Atomic weight. | | Specific density. | | Specific volume. |
|---|---|---|---|---|---|
| Lithium . . | 7 | ÷ | ·59 | = | 11·9 |
| Sodium . . | 23 | ÷ | ·97 | = | 23·7 |
| Potassium . | 39 | ÷ | ·86 | = | 45·3 |
| Rubidium . | 85 | ÷ | 1·52 | = | 56·0 |
| Cæsium . . | 133 | ÷ | 1·88 | = | 70·0 |

The acidic elements chlorine, bromine, and iodine, although differing greatly in atomic weight, have practically the same atomic volume in the liquid condition. If the densities of the elements were each determined at their several melting points instead of at mean temperatures, the specific volumes might possibly be more nearly identical. At any rate, the relative volumes determined show clearly that there is such a considerable kinetic energy of the atoms in the solid state that in building up the crystals of simple salts a dodecahedron may still be assumed as roughly representing an atom and its field of motion.

With minerals of diatomic constitution, as certain metallic sulphides, where the projecting pyramidal face of the metal is received by the inverse face of the sulphur, it is plain they

may crystallise in dodecahedral, or (which is the same thing) cubic, form. NaCl and ZnS are forced to crystallise thus by their molecular constitution.

The molecular structure of anhydrous crystals can readily be imitated, and acidic oxides can be united to basic oxides in the formation of crystalline salts, as the following carbonates, sulphates, and nitrates (assuming each atom contained in a *pentagonal* dodecahedron) will show.

Fig. 10 shows the arrangement of the atoms in calcium carbonate, which crystallises in rhombohedra. Calcium and carbon are in the vertical axis of the molecular crystal, and the three equal lateral axes pass through the atoms of oxygen shown separately in plan. A rhombohedron is really a distorted cube, and is one of those solids which will exactly fill space, so that if a rhombohedron is described on the molecule it will indicate the relative position of contiguous molecules, which build up the actual crystal shown separately in the figure.

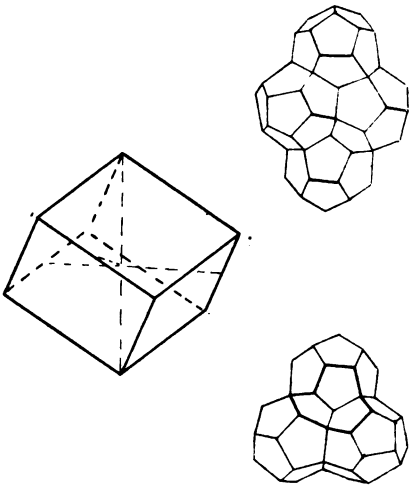


FIG. 10.

Fig. 11 shows a plan both from above and below of the atoms in a molecule of anhydrous calcium sulphate (anhydrite) which crystallises in unequal-sided tables. Calcium and sulphur are in the vertical axis of the molecular crystal, and the two unequal lateral axes each pass through two atoms of oxygen. In one view of the oxygen atoms a single dodecahedral space is shown by thick lines available for the acidic element; and on the reverse side calcium may occupy the

position between two similar spaces corresponding to its divalent properties. A typical crystal is also shown in the figure.

Although sodium nitrate is formed by the combination of $N_2O_5 + Na_2O$, it crystallises in rhombohedra similarly to calcium carbonate (Fig. 10), and therefore the molecule $NaNO_3$ has the same atomic arrangement as calcium carbonate, but

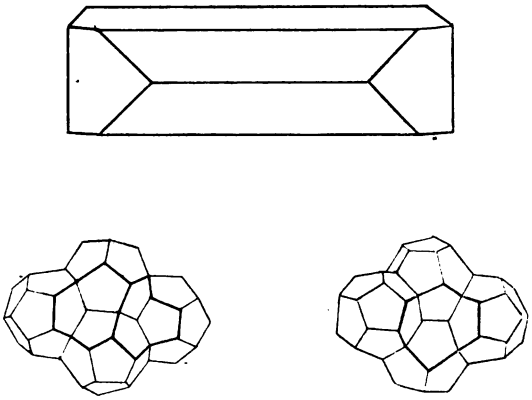


FIG. 11.

with sodium and nitrogen in the vertical axis of the molecular crystal.

These three crystals are typical of all the anhydrous carbonates and nitrates of the monad metals and the sulphates of the dyad metals.

Calcium sulphate is also crystallised with two molecules of water in gypsum, and the rectangular crystals of Fig. 11 then become rhombic; so that it may be concluded that each of the two addional atoms of oxygen attaches itself at the acute angle of the rhomb in the same plane as the four atoms of oxygen. Crystals complicated by such water of crystallisation are probably definite formations in most cases.

The mineral thenardite ($Na_2SO_4$) and the anhydrous crystals of ammonium and potassium sulphate ($(NH_4)_2SO_4$ and $K_2SO_4$),

each with two atoms of a monad element or radical in place of one dyad element, crystallise in the same system as calcium sulphate ($CaSO_4$), and thereby confirm the atomic formation of the sulphates, and also of that of sulphuric acid, from which they are derived.

It is evident that when a molecule of basic oxide is introduced into the characteristic hydrogen space formed by the hydroxyl radicals of an acid it is then in a position for annexing its required number of acid radicals.

The combining capacity of an acidic and also a metallic element no doubt affects its atomic volume and field of motion in the solid state. The tetrad carbon, for instance, with an atomic weight of 12, has about one-third the atomic volume of the monad lithium in the same series (*see* periodic table, page 15) with an atomic weight of 7. The tetradic bonds of carbon in methane ($CH_4$) were shown to be due to sixteen equi-radial monad atoms colliding with the one atom of carbon; and the peculiar shape of this atom, to which its combining properties are due, can just as well assert itself somewhat between atoms of its own species. There is a periodicity of the atomic volumes closely approximating to the periodicity of the elements, but this is best studied by the aid of a graphic curve, first constructed by Lothar Meyer, and to be found in most text-books. Carbon in the form of diamond has a smaller atomic volume than any other element.

The formation shown for the simple salts corresponds exactly with the formation obtained for the acids themselves, in which the hydroxyl radicals were shown to be the same for all acids, and the oxygen of these radicals are the main connecting links between the acidic and basic elements in the molecular crystals.

Diamond, the hardest known substance, and consisting of pure carbon, crystallises, in forms belonging to the cubic system, with an octahedral cleavage, and a characteristic of these crystals is that the octahedral forces are often slightly

convex, the angle between two of these convex or rounded faces being the cutting edge used by glaziers. A carbon atom has four corners, corresponding to the alternate angles of a cube, and if the atoms are arranged dodecahedrally, as described with reference to Fig. 5, the points *a* would each engage similar points *a* of three adjoining carbon atoms, or by a rearrangement as will be described with the organic compounds (ethane $C_2H_6$), the carbon atoms may engage each other by the facets *b*. A closer examination would, no doubt, reveal the exact formation.

Corundum ($Al_2O_3$), the next hardest known substance, will be convenient for describing a sesqui-oxide. An examination of diamond and corundum may eventually give an indication as to what hardness in a mineral really consists of. It must be remembered that hardness is usually associated with brittleness, and is therefore opposed to toughness, which is more a property of the metals and the nitrogenous compounds.

The spacial formation of a sesqui-oxide has already been described with reference to boric oxide, $B_2O_3$ (Fig. 6), and it remains to examine more particularly its resulting crystalline formation. Corundum is an anhydrous crystal of the rhombohedral system. Fig. 12 shows three rhombic dodecahedra, each with a dotted axis corresponding to the axis of an inscribed boron (Fig. 6) or aluminium atom, with no oxygen atom at the poles. The axes of three other dodecahedra are shown by full lines parallel to the dotted axes. The formation is such that at each of the remaining six corners of one dodecahedron, where four escribing dodecahedra meet, there is an oxygen atom. These six oxygen atoms, contiguous to any one aluminium atom, as will be seen in the figure, occur in alternating triplets, corresponding to the position of the faces in a circumscribing rhombohedron, and may thus account for the crystalline formation.

In aluminium sulphate, $Al_2(SO_4)_3$, the radical $SO_3$ attaches itself to each oxygen atom of the base. The exigences of

number indicate that the only possible atomic formation for the salt would be for a sulphur atom to replace each oxygen atom in the oxide, but surrounded by four oxygen atoms which interpose themselves between each of the four contiguous aluminium atoms. This salt does not form an anhydrous crystal, but with eighteen molecules of water corresponding to the formulæ $Al_2O_3$,$3SO_3$, $18H_2O$,it crystallises in silky efflorescences and crusts of a white colour. If the molecules of water are all similarly bound, the position of the oxygen atoms must necessarily be concentric with the oxygen of the base, and consequently with the $SO_3$ radicals also. The exact formation of a sesqui-oxide is interesting from the fact that it may in particular cases be either basic or acidic, and may be compared with the decidedly basic or acidic oxides. In the sulphate described it, of course, acts the part of a basic oxide.

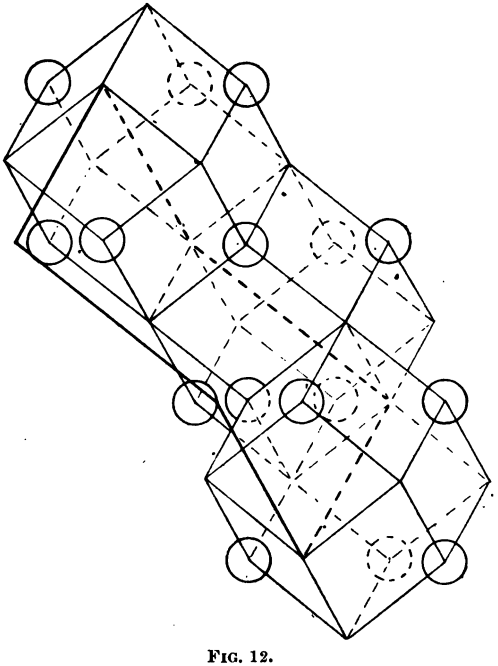


FIG. 12.

The sesqui-oxide is acidic in spinel ($Al_2O_3+MgO$), chrysoberyl ($Al_2O_3+BeO$); magnetic iron ore ($Fe_2O_3+FeO$), &c., and the basic oxide may possibly attach itself at the poles of the axes (Fig. 12), where there is no oxygen, but the resulting crystalline formation, although simple and definite, is by no means identical in each case.

## CHAPTER VI.

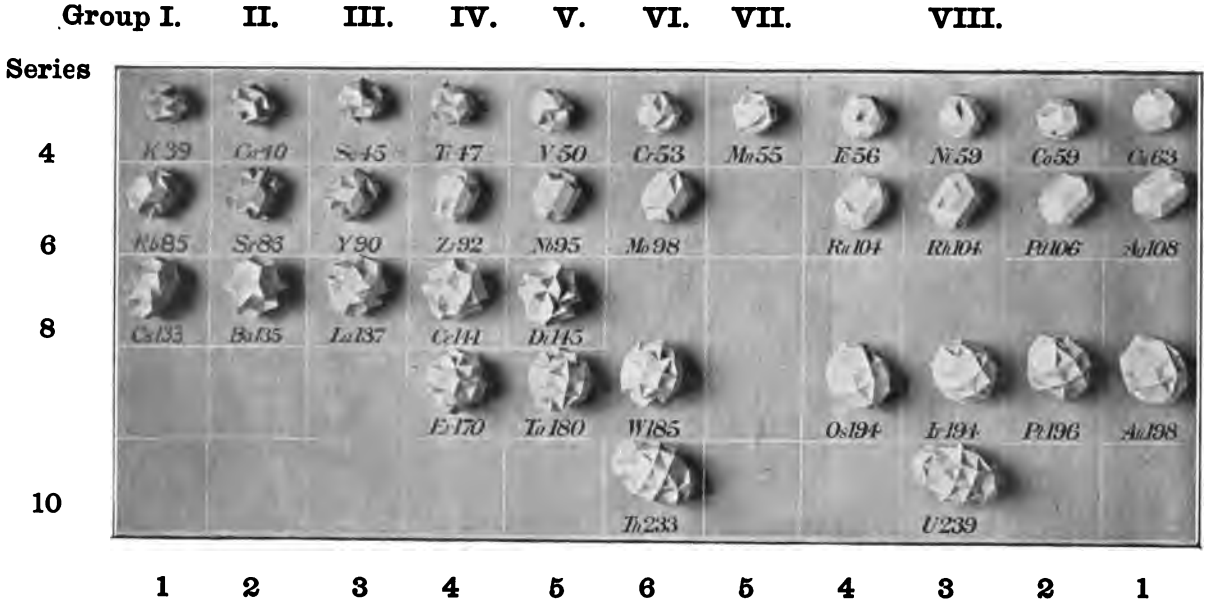
### MECHANICAL PHILOSOPHY OF THE METALS.

THE metals, which constitute the larger proportion of the elements, are distinguished by certain physical characteristics, the chief of which is, perhaps, *metallic lustre;* but they also readily conduct heat and electricity, are remarkable for a high degree of tenacity and malleability, and are mostly opaque. They are distinguished also by their chemical properties, as, with certain peculiar exceptions, they form basic oxides, which combine with and neutralise the acids. Their compounds with the acidic elements are remarkable for the energy displayed in the process of combination; in many cases with evolution of light and heat, and this is the ordinary phenomenon of *combustion.* Such compounds are remarkable for their stability and for the complete change in physical characteristics to that of the elements from which they are formed. But in compounds of metal with metals which are called *alloys* (or, where *mercury* is concerned, *amalgams*) no such physical change takes place; the resulting compound is still essentially metallic, and is easily reduced or broken up by chemical or physical agency.

The elements have been roughly divided at different periods into two great classes, namely, "metallic and non-metallic," from their physical characteristics; "basylous and acidulous" from their chemical behaviour; or "positive and negative, also called "zincous and chlorous," zinc and chlorine being representative elements, from their supposed electrical relations. The "metallic," "basylous," "positive," or "zincous" elements practically constitute one and the same class of

# PLATE III.

THE FOUR LONG SERIES WHOLLY METALLIC; BUT THE CENTRAL GROUPS WITH CERTAIN ACIDIC CHARACTERISTICS.



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element, to which is opposed the "non-metallic," "acidic," "negative," or "chlorous" class. Now it is remarkable that in the earlier chapter dealing with the exact shape of the elements zinc was shown to be the typical metal, having twelve complete pentagonal pyramidal (or positive) faces characteristic of the metallic atoms; and chlorine was shown to be the typical acidic element, having twelve complete inverse pyramidal (or negative) faces characteristic of the acidic atoms. It was also shown that as either the inverse or projecting pyramidal faces predominated, so the atom developed acidic or metallic characteristics. In that description the development of the acidic elements was carefully traced, and it now remains to examine the metals more particularly as a class.

The metals which commence each of the short series ending with acidic elements have been already described, and it will be seen by the following tables that they form very definite compounds, and are monads, dyads, triads, tetrads, or pentads exactly in accordance with their position in the periodic table as indicated by the Roman numerals at the head of each column.

| SERIES 2. | | | SERIES 3. | | |
|---|---|---|---|---|---|
| GROUP | | | GROUP | | |
| I. | II. | III. | I. | II. | III. |
| LiCl | $BeCl_2$ | $BCl_3$ | NaCl | $MgCl_2$ | $AlCl_3$ |
| $Li_2O$ | BeO | $B_2O_3$ | $Na_2O$ | MgO | $Al_2O_3$ |
| $Li_3N$ | | BN | NaO | | |
| | | $B_2S_3$ | $Na_2S$ | | $Al_2S_3$ |
| | $BeSO_4$ | — | $Na_2SO_4$ | $MgSO_4$ | $Al_2(SO_4)_3$ |
| | $Be(NO_3)_2$ | — | $NaNO_3$ | | |
| $Li_2CO_3$ | | — | $Na_2CO_3$ | $MgCO_3$ | |

| SERIES 5. | | | | SERIES 7. | | | | SERIES 9. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GROUP | | | | GROUP | | | | GROUP | | | |
| II. | III. | IV. | V. | II. | III. | IV. | V. | II. | III. | IV. | V. |
| $ZnCl_2$ | $GaCl_3$ | $GeCl_4$? | $AsCl_3$ | $CdCl_2$ | $InCl_3$ | $SnCl_2$<br>$SnCl_4$ | $SbCl_3$<br>$SbCl_5$ | HgCl<br>$HgCl_2$ | TlCl<br>$TlCl_3$ | $PbCl_2$<br>$PbCl_4$ | $BiCl_3$<br>$BiCl_2$ |
| ZnO | $Ga_2O_3$ | $GeO_2$? | $As_2O_3$<br>$As_2O_5$ | CdO | $In_2O_3$ | SnO<br>$Sn_2O_3$<br>$SnO_2$ | $Sb_2O_3$<br>$Sb_2O_5$<br>$(Sb_2O_4)$ | $Hg_2O$<br>HgO | $Tl_2O$<br>$Tl_2O_3$ | $Pb_2O$<br>PbO<br>$Pb_2O_3$<br>$PbO_2$<br>$Pb_3O_4$ | $Bi_2O_3$<br>$Bi_2O_5$<br>$(Bi_2O_4)$ |
| ZnS | | | AsS<br>$As_2S_3$ | CdS | | SnS<br>$Sn_2S_3$<br>$SnS_2$ | $Sb_2S_3$<br>$Sb_2S_5$ | $Hg_2S$<br>HgS | | PbS | $Bi_2S_3$ |
| $ZnSO_4$ | $Ga_2(SO_4)_3$ | — | — | $CdSO_4$ | $In_2(SO_4)_3$ | — | — | $Hg_2SO_4$<br>$HgSO_4$ | $Tl_2SO_4$<br>$Tl_2(SO_4)_3$ | $PbSO_4$ | $Bi_2(SO_4)_3$ |
| $Zn(NO_3)_2$ | | | | | $In(NO_3)_3$ | — | — | $HgNO_3$<br>$Hg(NO_3)_2$ | | $Pb(NO_3)_2$ | $Bi(NO_3)_3$ |
| $ZnCO_3$ | | | | | | | | | $Tl_2CO_3$ | $PbCO_3$ | |

The foregoing tables give the chlorides, oxides, sulphides, and nitrides which each element is actually known to form, and also its sulphates, nitrates, and carbonates. The valency of a metallic element is mostly determined by its highest chloride, but arsenic, for instance (Series 5), does not form a penta-chloride, so that its maximum valency is indicated by the oxide $As_2O_5$. It will be noticed that as an element develops acidic characteristics it ceases to form sulphates, nitrates and carbonates; but in place of these boron, germanium, arsenic, tin, antimony and lead form their own oxygen salts, mostly (except in the case of lead and germanium) with corresponding acids from which they may be derived, as shown by the next table.

| | Boron. | Germanium. | Arsenic. | Tin. | Antimony. | Lead. |
|---|---|---|---|---|---|---|
| Acids. | $H_3BO_3$<br>$H_2B_2O_4$<br>$H_2B_4O_7$ | — | $H_3AsO_4$<br>$H_4As_2O_7$<br>$HAsO_3$ | $H_2SnO_3$<br>$H_{10}Sn_5O_{15}$ | $H_3SbO_4$<br>$H_4Sb_2O_7$<br>$HSbO_3$ | — |
| Salts. | $K_2B_2O_4$<br>$Na_2B_4O_7$<br>$Ca_2B_6O_{11}$ | Forms germanates corresponding to the silicates. | $Ag_3AsO_4$<br>$Ca_2As_2O_5$<br>$KAsO_2$<br>$Pb(AsO_2)_2$ | $Na_2SnO_3$<br>$K_2SnO_3$<br>$K_2SnO_3, 4SnO_2, 4H_2O$<br>$Na_2SnO_3, 4SnO_2, 4H_2O$ | $K_4Sb_2O_7$<br>$KSbO_3$<br>$Ba(SbO_3)_2$ | $K_2PbO_3$ |

These salts are all formed with the strongly basic oxides only, except in the case of arsenic, which is more acidic than metallic. The salts are known as orthoboric, metaboric, pyroboric, germanates, arsenates, arsenites, stannates, metastannates, antimonates, plumbates, &c.

It will now be convenient to describe the shape of the atoms in the four long series Nos. 4, 6, 8, and 10 of the periodic table.

Plate III. is a photograph of models of these atoms agreeing (by the number of tetrahedrons of which each atom is composed) as nearly as possible with the observed atomic

weights of the elements, but with slight variations in certain cases to obtain symmetrical and uniform variations in shape.

The No. 8 series is exceptionally long, as it includes a special short series ending with didymium (145), in which the added tetrahedra are attached to the sides or girdle-belt of the atom instead of to the twelve pentagonal faces only, as in the previous long series Nos. 4 and 6. Between didymium and the end of this series are some rare earth metals which have not yet been isolated, but are known to exist in combination; their atomic weights correspond to the point where the girdle-belt of mercury first assumes its complete form, and the gradual formation of this belt may be readily traced in the models shown in the plate.

The No. 10 series at present includes only two members. The discovery of a metal of atomic weight 245, which may be called "zadmium," would confirm the existence of this series and form a natural termination to the whole of the elements.

The chlorides, oxides, sulphides, and nitrides actually formed from the metals of the three complete series Nos. 4, 6, and 8, and also their sulphates, nitrates, and carbonates, are shown in the following tables:

SERIES 4.

| GROUP I. | II. | III. | IV. | V. | VI. | VII. | VIII. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Ni | Co | Cu |
| KCl | $CaCl_2$ | | $TiCl_3$<br>$TiCl_4$ | $VCl_2$<br>$VCl_3$<br>$VCl_4$<br>$VOCl_3$ | $CrCl_2$<br>$CrCl_3$<br>$CrF_6$ | $MnCl_2$<br>$MnCl_3$ | $FeCl_2$<br>$FeCl_3$ | $NiCl_2$ | $CoCl_2$<br>$CoCl_3$ | CuCl<br>$CuCl_2$ |
| $K_2O$<br>KO<br>$KO_2$ | CaO<br>$CaO_2$ | $S_2O_3$ | $Ti_2O_3$<br>$TiO_2$ | $V_2O$<br>VO<br>$(V_2O_3)$<br>$VO_2$<br>$(V_2O_5)$ | CrO<br>$Cr_2O_3$<br>$(Cr_3O_4)$<br>$CrO_2$<br>$CrO_3$ | MnO<br>$(Mn_2O_3)$<br>$(Mn_3O_4)$<br>$MnO_2$<br>$MnO_3$<br>$Mn_2O_7$? | FeO<br>$Fe_2O_3$<br>$(Fe_3O_4)$ | NiO<br>$Ni_2O_3$ | CoO<br>$Co_2O_3$<br>$(Co_3O_4)$ | $Cu_4O$<br>$Cu_2O$<br>CuO<br>$CuO_2$ |
| $K_2S$<br>KS<br>$(K_2S_3)$<br>$KS_2$<br>$(K_2S_5)$ | CaS<br>$CaS_2$<br>$CaS_5$ | | | $VS_2$<br>$V_2S_5$ | | | FeS<br>$FeS_2$<br>$Fe_3S_4$ | | | CuS<br>$Cu_2S$ |
| | CaP | | $Ti_3N_4$? | VN<br>$VN_2$ | $Cr_3N_4$? | | | | | |
| $K_2SO_4$ | $CaSO_4$ | $Sc_2(SO_4)_3$ | — | $V_2O_2(SO_4)_2$ | $Cr_2SO_4$ | $MnSO_4$<br>$Mn_2(SO_4)_3$ | $FeSO_4$<br>$Fe_2(SO_4)_3$ | $NiSO_4$ | $CoSO_4$ | $CuSO_4$ |
| $KNO_3$ | $Ca(NO_3)_2$ | $Sc(NO_3)_3$ | — | — | | | $Fe(NO_3)_2$<br>$Fe(NO_3)_3$ | | | $Cu(NO_3)_2$ |
| $K_2CO_3$ | $CaCO_3$ | $Sc_2(CO_3)_3$ | — | — | | $MnCO_3$ | $FeCO_3$ | $NiCO_3$ | $CoCO_3$ | $CuCO_3$ |
| 1 | 2 | 3 | 4 | 5 | 6 | 5 | 4 | 3 | 2 | 1 |

SERIES 6.

| Group I. | II. | III. | IV. | V. | VI. | VII. | VIII. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rb | Sr | Y | Zr | Nb | Mo | — | Ru | Rh | Pd | Ag |
| RbCl | $SrCl_2$ | | ZrF | $NbCl_5$ | $MoCl_2$<br>$MoCl_3$<br>$MoCl_4$<br>$MoCl_5$ | | $RuCl_2$<br>$RuCl_3$<br>$RuCl_4$ | $RhCl_3$ | $PdCl_2$<br>$PdCl_4$ | $AgCl_2$<br>AgCl |
| $Rb_2O$? | SrO<br>$SrC_2$ | $Y_2O_3$ | $ZrO_2$ | $Nb_2O_5$ | MoO<br>$MoO_2$<br>$MoO_3$ | | RuO<br>$(Ru_2O_3)$<br>$RuO_2$<br>$(RuO_3)$<br>$(Ru_2O_7)$<br>$RuO_4$ | RhO<br>$Rh_2O_3$<br>$RhO_2$ | PdO<br>$PdO_2$ | $Ag_4O$<br>$Ag_2O$<br>AgO |
| | | | | | $MoS_2$<br>$MoS_3$<br>$MoS_4$ | | $Ru_2S_3$<br>$RuS_2$ | | PdS | $Ag_2S$ |
| | $SrSO_4$ | $Y_2(SO_4)_3$ | $Zr(SO_4)_2$ | — | — | | — | $Rh_2(SO_4)_3$ | — | $Ag_2SO_4$ |
| | $Sr(NO_3)_2$ | ? | | — | — | | — | | — | $AgNO_3$ |
| $Rb_2CO_3$? | $SrCO_3$ | | | — | — | | — | | — | $Ag_2CO_3$ |
| 1 | 2 | 3 | 4 | 5 | 6 | 5 | 4 | 3 | 2 | 1 |

SERIES 8.

| GROUP I. | II. | III. | IV. | V. | V. | VI. | VII. | VIII. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cs | Ba | La | Ce | Di | Ta | W | — | Os | Ir | Pt | Au |
| $CsCl$ ? | $BaCl_2$ | $LaCl_3$ | $CeCl_3$<br>$CeF_4$ | | $TaCl_5$ | $WCl_2$<br>$WCl_4$<br>$WCl_5$<br>$WCl_6$ | | $OsCl_2$<br>$OsCl_3$<br>$OsCl_4$ | $IrCl_2$<br>$Ir_2Cl_3$<br>$IrCl_4$ | $PtCl_2$<br>$PtCl_4$ | $AuCl$<br>$AuCl_3$ |
| $Cs_2O$ ? | $BaO$<br>$BaO_2$ | $La_2O_3$ | $Ce_2O_3$<br>$CeO_2$ | $Di_2O_3$<br>$Di_2O_5$ | $TaO_2$<br>$Ta_2O_5$ | $WO_2$<br>$WO_3$<br>$(W_2O_5)$ | | $OsO$<br>$(Os_2O_3)$<br>$OsO_2$<br>$OsO_3$<br>$OsO_4$ | $IrO$<br>$(Ir_2O_3)$<br>$IrO_2$ | $PtO$<br>$PtO_2$ | $Au_2O$<br>$Au_2O_3$ |
| | $BaS$ | | | | $TaS_2$ | $WS_2$<br>$WS_3$ | | $OsS$<br>$(Os_2S_3)$<br>$OsS_2$<br>$OsS_3$<br>$OsS_4$ | $IrS$<br>$(Ir_2S_3)$<br>$IrS_2$ | $PtS$<br>$PtS_2$ | $Au_2S$<br>$AuS$ |
| | $BaSO_4$ | $La_2(SO_4)_3$ | $Ce_2(SO_4)_3$<br>$Ce(SO_4)_2$ | $Di_2(SO_4)_3$ | — | — | | $(OsSO_3)$ | $Ir(SO_3)_3$ | — | — |
| | $Ba(NO_3)_2$ | | | $Di(NO_3)_3$ | — | — | | — | — | — | — |
| $CsCO_3$ ? | $BaCO_3$ | | | | — | — | | — | — | — | — |
| 1 | 2 | 3 | 4 | 5 | 5 | 6<br>5 | 5 | 4 | 3 | 2 | 1 |

E

The metals in the centre of each of these series develop acidic properties, and do not all form sulphates, nitrates, carbonates, &c., but have their own oxygen salts, as the vanadates, chromates, manganates, permanganates, niobdates, molybdates, ruthenates, tantalates, tungstates, osmates, &c., mostly without corresponding acids, as shown in the table:—

| | Vanadium. | Chromium. | Manganese. | Niobium. | Molybdium. |
|---|---|---|---|---|---|
| Acids. | $HVO_3$<br>$H_4V_2O_7$ | $H_2CrO_4$ | $H_2MnO_4$<br>$HMnO_4$ | | |
| Salts. | $NaVO_3$<br>$Pb_3(VO_4)_2$<br>$BiVO_4$ | $K_2CrO_4$<br>$K_2Cr_2O_7$<br>$CaCrO_4$ | $K_2MnO_4$<br>$KMnO_4$ | $NaNbO_3$ | $PbMoO_4$<br>$Na_2Mo_2O_7$ |

| | Ruthenium. | Tantalum. | Tungsten. | Osmium. |
|---|---|---|---|---|
| Acids. | — | | $H_2W_4O_{13}$ | — |
| Salts. | $K_2RuO_4$<br>$KRuO_4$ | $NaTaO_3$ | $Na_2W_2O_7$<br>$PbWO_4$ | $K_2OsO_4$ |

The metallic mono-, di-, tri-, and tetra-chlorides are mostly stable compounds, even in the gaseous condition, but some of the tetra-chlorides and all the penta- and hexa-chlorides give up part of their chlorine when heated. The mono-, di-, tri-, and tetra-chlorides must therefore be analogous to the hydrides of the acidic elements, and have the atoms arranged in relatively similar positions; and this will account for the gaseous chlorides occupying similarly two relative volumes. Even in the hydrides of the acidic elements the hydrogen atoms may have the hydrogen partially or totally replaced by chlorine, although the product is very unstable and liable to decomposition with explosive violence, as nitrogen trichloride ($NCl_3$), &c.

The gaseous metallic monochloride, as potassium chloride

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(KCl), will have the atoms arranged as in hydrochloric acid (HCl), with the hydrogen replaced by potassium.

The gaseous metallic dichloride, as zinc chloride ($ZnCl_2$), will have the atoms arranged, as in water ($OH_2$), with the oxygen replaced by the metal and the hydrogen by chlorine. Each atom of zinc will collide with eight different atoms of chlorine, radially equidistant, and each pair of chlorine atoms will similarly collide with eight different atoms of zinc.

The gaseous metallic trichloride, as boron trichloride, will have the atoms arranged as described for boron trihydride, with the hydrogen replaced by chlorine, which gives in this particular instance a more definite and stable compound. Each atom of boron will collide with twelve different atoms of chlorine, radially equidistant, and each atom of chlorine will similarly collide with four different atoms of boron.

The gaseous metallic tetrachloride, as stannic chloride ($SnCl_4$) will have the atoms arranged as described for carbon tetrahydride ($CH_4$), with the carbon replaced by the metal and the hydrogen by chlorine. Each atom of tin will collide with sixteen different atoms of chlorine, and each atom of chlorine will collide with four different and radially equidistant atoms of tin. There cannot be sixteen radially equidistant atoms of chlorine, as there is no regular geometrical solid with sixteen faces, and the chlorine in a tetrachloride must assume the special arrangement described for the hydrogen atoms in carbon tetrahydride. Where the shape of the metallic atom is unsuitable for supporting this special arrangement, as it may be assumed is the case with lead in the tetrachloride $PbCl_4$ (or $PtCl_4$ and $PtCl_2$), the compound will not volatilise without yielding up part of its chlorine.

On referring to the tables in this chapter it will be seen that there are also pentachlorides and hexachlorides, or their equivalents. These chlorides do not volatilise without giving up part of their chlorine, and moreover it is a geometrical impossibility for the chlorine atoms of penta- and hexa-chlorides to be in such a position that each may collide

with four different atoms of the metal, as described in the di-, tri-, and tetra-chlorides. The only possible arrangement seems to be that described for the acidic oxides, nitrogen pentoxide ($N_2O_5$), or sulphur trioxide ($SO_3$), for example, where the oxygen collides with only two different atoms of the acidic element, and the acidic element collides with the number of oxygen atoms in the two-atom molecule $N_2O_5$ and $S_2O_6$, in one case with five and in the other with six. A pentachloride would therefore have to collide with ten different atoms of the metal and a hexachloride with twelve. Such a geometrical arrangement will necessitate spaces between the chlorine atoms unoccupied by a metal just as described for the acidic oxides; and these chlorides would necessarily have the more or less dodecahedral arrangement which is peculiar to the atoms of a liquid or solid, and they could not be volatilised and assume a gaseous arrangement without decomposition.

The models of the metallic atoms exhibited in Plate III. are the most regular shapes that can be obtained approximating to their experimentally determined atomic weight by the number of tetrahedrons of which each is composed. They were made to satisfy these conditions without any reference whatever to their combining properties, as were all the other atomic models herein described, including those representative atoms—oxygen, nitrogen, and carbon—whose several combinations with hydrogen are mechanically perfect. Yet it is found on examining the pentad and hexad metals that the one has ten symmetrical sinkings and the other twelve, just as required in the penta- and hexa-chlorides.

**Arsenic, antimony,** and **bismuth** (Series 5, 7, and 9) are pentads, but only antimony forms a pentachloride. The trichlorides of this group are the same as described for all the trichlorides with twelve chlorine atoms radially equidistant from the metal.

**Vanadium** (Series 4) is not known to form a pentachloride, but the oxychloride $VOCl_3$ is supposed to be an equivalent,

as one atom of oxygen will displace two of chlorine. Th atomic model (Plate III.), with an atomic weight of 50, has the ten symmetrical sinkings required. The observed atomic weight of vanadium is 51.

**Chromium** (Series 4) forms a hexafluoride analogous to a hexachloride, and the atomic model (Plate III.), with an atomic weight of 53, has the twelve required symmetrical sinkings. The observed atomic weight of chromium is 53

**Niobium** (Series 6) forms a pentachloride, and the atomic model (Plate III.), with an atomic weight of 95, has the ten symmetrical sinkings similarly to vanadium. The observed atomic weight of niobium is 94.

**Molybdenum** (Series 6) forms di-, tri-, tetra-, and penta-chlorides, but the hexachloride is not known. It should be capable of forming a hexachloride if its atom corresponds to the shape shown in Plate III., which has twelve symmetrical sinkings, similar to chromium, and an atomic weight of 98. The observed atomic weight of molybdenum is 96.

**Didymium** and **tantalum** (Series 8) occur at the point where the girdle-belt peculiar to mercury and the allied elements is first formed. The first effect of this belt is to accentuate ten of the twelve sunk faces, so as to form penta-chlorides. Tantalum forms a pentachloride, but the chlorides of didymium are unknown, although the oxide $Di_2O_5$ indicates that it should also form a pentachloride. The weights corresponding to the atomic models shown for didymium and tantalum are 145 and 180 respectively, as against 147 and 182 the observed atomic weights.

**Erbium** (Series 8) is also shown in Plate III., with an atomic weight of 170, and it should evidently also be a pentad. It appears to be triadic and tetradic in some of its compounds, and the observed atomic weight is 169.

**Tungsten** (Series 8) forms a di-, tetra-, penta-, and also a hexa-chloride. The position of the chlorine atoms must be conditioned by the ten faces accentuated by the girdle-belt (as before mentioned), as the succeeding metals, osmium, iridium,

and platinum, in which these faces are filled up, do not form penta-chlorides. For the same reason the hexachloride must have the position of the chlorine atoms conditioned by the twelve sunk faces which are filled up in the atoms of the same succeeding metals. The atomic weight of tungsten corresponding to the model shown is 185, while the observed atomic weight is 184.

There is no evidence to show that there are any higher chlorides than the hexachlorides, and on examining the tables of Series 4, 6, and 8 it will be seen that the remainder of the elements, namely, Cr, Mn, Fe, Ni, Co, Cu, in Series 4; Mo, —, Ru, Rh, Pd, Ag, in Series 6; and W, —, Os, Ir, Pt, Au, in Series 8, form, at least as far as the chlorides are concerned, a descending series quite as much as the first six elements is an ascending one.

The only known metal in Group VII. is manganese (Series 4), from which the heptoxide $Mn_2O_7$ has been obtained. This is the oxide corresponding to permanganic acid $HMnO_4$, or $H_2O+Mn_2O_7$, and indicates that manganese is a heptad; but this oxide and also the acid is very unstable, and only forms stable compounds with alkaline oxides, which may be supposed to have a sort of residual valency (as indicated by their numerous binary compounds), so that the stability of a salt such as potassium permanganate, $KMnO_4$, is as much due to the residual valency of potassium as to the septavalency of manganese.

A point of great interest has now been reached and may be elucidated by comparing manganous sulphate, $MnSO_4$, with potassium manganate $K_2MnO_4$ and the permanganate $KMnO_4$. With $KMnO_4$ the manganese is septavalent and probably collides with fourteen different atoms of oxygen, in which it must be assisted by the atomic shape of potassium, and this is a much more stable compound than the manganate $K_2MnO_4$. In manganous sulphate, $MnSO_4$, the sulphur being hexadic and much more strongly acidic, collides with perhaps twelve different atoms of oxygen, while the action of the

manganese atom is simply to occupy the acidic space provided by the radical $SO_4$.

This is typical of what occurs with most of the metals of Groups IV., V., VI., VII., and with osmium of Group VIII. The symmetrical sinkings (mostly ten or twelve in number) compete with the characteristic sunk faces of the acidic elements, and while they are not sufficient to make the metal form a binary compound with hydrogen, and scarcely to form a stable oxygen acid, yet they are sufficient, perhaps, to prevent the formation of a sulphate, nitrate, or carbonate (as clearly shown in the tables of the actual compounds formed in each series), and instead thereof may form very stable salts, if assisted by the peculiar atomic shapes of the light metals of Groups I. and II. These salts have been already shown by typical examples, on a separate table, with their corresponding acids, if any exist.

The same thing, of course, occurs with Series 5, 7, and 9. Arsenic and antimony, for instance, form their own metallic salts, and also corresponding acids, as shown by a separate table, and cannot themselves be converted into sulphates, nitrates, or carbonates.

The metals of Group VIII. are usually considered in the periodic classification to be octads because of the tetroxides of ruthenium and osmium, $RuO_4$ and $OsO_4$, but it is possible the atomic shape of the Series 6 and 8 in which these two elements occur, and together called the platinum group, is such that the differing combining capacity of chlorine and oxygen is neutralised, at least so far as liquid and solid compounds are concerned, and the chlorine and oxygen atoms occupy exactly similar positions in their chlorides and oxides. The chlorides of the platinum group are remarkable for the fact that they unite with the chlorides of the alkali metals, and also with ammonia to form anhydrous crystalline salts, and in this way are exactly analogous to the oxides of the other elements. The oxides of the same group are of comparatively small importance; so that it is clear that for this

particular group of metals chlorine has usurped the place of oxygen, and therefore the tetroxides of ruthenium and osmium are by no means analagous to *octa*chlorides, and there is no other evidence to show that there are octads in Group VIII., although in the chloride salts referred to, such as potassium platino-chloride, $Cl_4Pt(KCl)_2$, the platinum is supposed to be united with eight univalent atoms. This is merely a theoretical supposition, but if the chlorine, as suggested, has really taken the same place as oxygen, in the oxygen salts, then in these particular compounds chlorine must be regarded as a dyad; but the potassium must be dyadic also to make platinum an octad, but this question altogether vanishes when the exact shape of the atoms and their relative arrangement in space is known.

The chlorine atoms of the penta- and hexa-chlorides, it will be remembered, inevitably collide with only two atoms of the metal, just like the oxygen atoms in the acidic oxides, and they could not be volatilised without decomposition. The di-, tri-, and tetra-chlorides of the platinum group likewise cannot be volatilised without decomposition, so the description already given for the relative position of the atoms in gaseous chlorides will not apply to the penta- and hexa-chlorides, they must, therefore, have the more or less dodecahedral arrangement peculiar to the liquid or solid condition, and each atom of chlorine must inevitably collide with only two atoms of the metal, and therefore, these chlorides must be characterised by alternate empty spaces, just as described for the acidic oxides. This description no doubt applies to the liquid or solid polychlorides of the other elements, but in this case the elongation of the axis of each atom in the platinum group, no doubt, renders the acidic spaces more pronounced, so that it may be more readily neutralised by a basic or monochloride. Chlorine being a monad element, there is only one basic chloride—the monochloride. Any dichloride would be weakly acidic in residual combining capacity, just like a dioxide.

The salts of the platinum group are also remarkable for their numerous compounds with ammonia, as $2(NH_3)PtCl_2$ for instance, in which a hydrogen atom of $NH_4$ is apparently replaced by the metal. Ammonium may also take the place of sodium or potassium in the double salts, as $K_2PtCl_4$, $(NH_4)_2PtCl_4$; $Na_2PtCl_6$, $(NH_4)_2PtCl_6$.

On examining the three long series of metals, Nos. 4, 6, and 8, it will be noticed that each series commences with the light metals as potassium, rubidium, cæsium, calcium, strontium, barium, in which the characteristic metallic faces are represented by, say, one tetrahedron, and are merely skeleton faces, as it were, and these are the metals that are only reduced from their oxides with great difficulty. The centre portion of each series is occupied by the peculiar metallic elements with acidic properties already described; and the end of each series is formed by the heavy metals which are easily reducible from their oxides, and their atomic shapes are characterised by the more or less complete pyramidal faces characteristic of the metals. The abnormal number of elements in Series 8 has also been satisfactorily accounted for. The mechanical philosophy of the metals (as was also the case with the acidic elements), therefore, agrees absolutely with the physical and chemical requirements.

It is difficult at present to account for the tenacity of metals by any mode of atomic motion, but some indication is perhaps given by the nomadic hydrogen of the tough nitrogenous compounds. It should also be noted that, while heat will destroy that tenacity, so also, at the extremely low temperature now obtainable by means of liquid air, a piece of steel wire may be snapped off short like a carrot. The fact that hydrogen gas will penetrate platinum and iron tubes at a red heat may possibly give some clue to the atomic motions of the metal. An experiment has been performed by clamping the bright faces of two blocks of metal together, such as gold and lead under pressure. After a time the gold is found to permeate the bulk of the lead, and likewise the

lead to permeate the gold. This is supposed to be due to electrical action ; which may be true, but it does not alter this supposition to say that it is due to atomic motion, and is a parallel phenomenon to the diffusion of gases. The peculiar metallic lustre may evidently be satisfactorily accounted for by the projecting pyramidal faces, the lustre being more durable and pronounced as these faces are the more complete in any given atom.

## CHAPTER VII.

### ORGANIC CHEMISTRY.

By the systematic formation of the atoms of the whole of the elements a remarkable trio of atoms—carbon, nitrogen, and oxygen—has been obtained of the exact atomic weight as determined by experiment. Every pentagonal face of the icosahedron on which these atoms are built (and there are twelve possible ones overlapping), has four, three, or two facets as the case may be, unoccupied by projecting tetrahedra, and these numbers—four, three, and two, respectively, correspond with the combining capacities of carbon, nitrogen, and oxygen with hydrogen. It is impossible adequately to express the significance of the perfect relationship here apparent; but a mechanical equivalent for the "bonds" of the ordinary structural formulæ is immediately obtained thereby.

Carbon, nitrogen, oxygen, and hydrogen form practically the whole of the exceedingly numerous compounds of organic chemistry; and these compounds may also be derived directly or indirectly from the numerous compounds of carbon and hydrogen alone. Furthermore, as hydrogen is a monad metallic element, it simply occupies the spaces formed by the quadrivalent element, carbon; so that if the relative position of the carbon atoms can be obtained in a complex organic compound, the relative position of the other elements in the same compound can be deduced.

The principal series of hydrocarbons may be summarised as follows:

| | Lowest member. | |
|---|---|---|
| Methane series . . | $CH_4$ | + $nCH_2$ |
| Olefine series . . | $CH_2$ | + $nCH_2$ |
| Acetylene series . | $C_2H_2$ | + $nCH_2$ |
| Benzene series . . | $C_6H_6$ etc. | |

A rhombic dodecahedron, which has interfacial angles of 90° where six solids meet, and 120° where four solids meet, will exactly fill space if a number of them are placed together

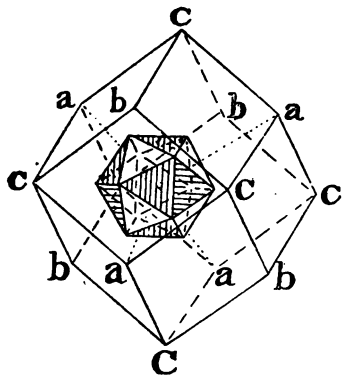


FIG. 13.

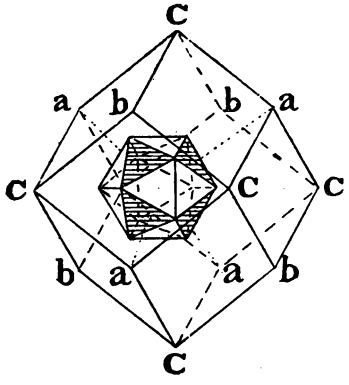


FIG. 14.

with coincident faces; and by noting and numbering the different faces and solid angles it is possible to accurately plan out the relative position of the different atoms.

In Fig. 15, showing an atom of carbon with an escribed dodecahedron, it may be noted that of the eight solid angles where three faces or four solids meet, four are over the carbon points, *a* (indicated only by hatched facets), and four are over the similarly situated four facets, *b*. In Fig. 13, showing an atom of oxygen with an escribed dodecahedron, the same eight solid angles, *a* and *b*, are over the similarly placed eight facets. In Fig. 14, showing an atom of nitrogen with an escribed dodecahedron, the eight solid angles *a* and *b* are occupied by the similarly placed eight projecting tetrahedra (indicated by hatched facets) of the nitrogen atom. In all of these figures the remaining six solid angles, C, of the escribed

dodecahedron are over six identical pairs of facets on each atom.

The relative arrangement of the atoms in methane or carbon tetrahydride ($CH_4$) has already been described, but it may here be noted that the hydrogen atoms are arranged tetrahedrally to each carbon atom, and are forced by contiguous hydrogen atoms, each to take a position indicated by the four facets, *b*, of each carbon atom; the remaining three facets of three different carbon atoms necessary for enclosing each of these hydrogen atoms are one of the remaining twelve, or six pairs, *C*, which are contiguous on each carbon atom to both the facets, *b*, and the bases of the tetrahedra, *a*. A definite molecule is now obtained, but caused, not by the mutual attraction of its constituent atoms, but by the position and movements of similar adjacent molecules.

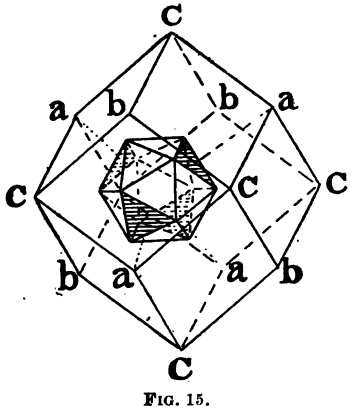

FIG. 15.

A carbon atom may be inserted at the four solid angles *b*, in the more or less tetrahedral spaces, each occupied by four hydrogen atoms with four facets, *b*, of the original carbon atoms exactly facing, and colliding with the similar four facets, *b*, of the additional carbon atoms. Every carbon atom then collides with four radially equidistant carbon atoms besides twelve different hydrogen atoms; and this constitutes the mechanical equivalent of a single bond between the carbon atoms, the remaining three bonds being satisfied with hydrogen. In spite of the re-arrangement, the space occupied by each hydrogen atom is still tetrahedral, and they each collide with four facets of four different carbon atoms as before, but the compound is now ethane, $C_2H_6$ or $CH_3$—$CH_3$. It will be found that the four points of carbon are simply accessory to the twelve facets which surround the bases of

the four tetrahedra, just as the similar eight projecting tetrahedra of nitrogen were found to be accessory to the facets at the base in the description of ammonia, $NH_3$.

A third carbon atom may be inserted at the four solid angles, *a*, of the rhombic dodecahedron, escribing the original carbon atom with its points, *a*, engaging the similar points *a* of the No. 1 carbon, and its facets, *b*, engaging the points *a* of the No. 2 carbon, giving the arrangement of the atoms in propane, $C_3H_8$ or $CH_3—CH_2—CH_3$. If instead of a third carbon atom an atom of oxygen is inserted, its four facets, *b* (Fig. 13) will engage the points *a* of the No. 1 carbon, and its remaining four facets, *a*, will face the four points, *a*, of the No. 2 carbon, giving the arrangement of the atoms in methyl ether $CH_3—O—CH_3$. This arrangement with eight radially equidistant carbon atoms evidently constitutes the double bond of O or $CH_2$. The carbon atom in the $CH_2$ radical still has twelve facets unaccounted for, and these are the six pairs of facets previously referred to, which occur at the six solid angles of the escribed dodecahedron (Fig. 15), where four faces, or six contiguous solids, meet; and the contiguous carbon points of the $CH_3$ radicals have likewise been utilised for a double bond in place of a facet, so that the hydrogen of the $CH_2$ radical collides with six facets of six different adjacent carbon atoms. If an oxygen atom replaces the radical $CH_2$, the six pair of facets of the carbon are replaced by points, and the position becomes untenable for two hydrogen atoms, as in methyl ether just described. If the two hydrogen atoms of the radical $CH_2$ are replaced by oxygen, the six pairs of facets C of this atom (Fig. 13 and frontispiece) must engage the six pairs of facets C of the adjoining carbon atoms (Fig. 15). This is what occurs in acetone $CH_3—CO—CH_3$, and is a type of the class of organic compound called "ketones." Ketones are distinguished from aldehydes as the oxygen in an aldehyde displaces hydrogen from the methyl group $CH_3$.

An additional carbon atom can be similarly placed succes-

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sively at the four points, *b*, of the rhombic dodecahedron, escribing the original carbon atom, and also at the similar points with respect to the No. 2 methyl carbon, each time obtaining the double bond as just described, and thus the homologous methane series $CH_3—CH_2—nCH_2—CH_3$ of the carbon compounds is obtained. A homologous series is one in which the members vary by $n$ times $CH_2$, and is not merely confined to the hydrocarbons, but applies also to the chlorides, alcohols, aldehydes, ketones, acids, &c., which may be derived from them. The melting points of some of these homologous series (formic and succinic acid series)* do not uniformly vary with increasing carbon, but alternately rise and fall accordingly as the number of carbon atoms is odd or even, but if the odd or even series is considered separately, the rise or fall is continuous. The alternate addition of the carbon atom at the points *a*, and at the points *b* of the escribed dodecahedron, may very well account for the alternate variation of the melting point, as a lower melting point may be caused by a more symmetrical arrangement.

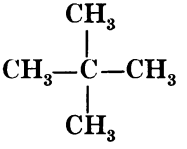
Besides the open-chain series as $CH_3—CH_2—CH_2—CH_3$, the last additional $CH_2$ can form a side chain as in trimethyl-methane.

$$\begin{array}{c} CH_3—CH—CH_3 \\ \quad\quad | \\ \quad\quad CH_3 \end{array}$$

The additional carbon atom cannot enter at either of the solid angles *a* and *b* of the dodecahedron, escribing the methane radical as these are the relative positions occupied by the $CH_3$ radicals in the formation of the open chain-series. It must, therefore, enter at the remaining six points, where four faces or six escribing solids meet. It will be found that these six points are really six pairs of points, each pair formed by six pairs of facets of six adjacent carbon atoms; six of these points would be occupied by the $CH_3$

* See "Berichte der Deutschen Chemischen Gesellschaft" or "Recueil des travaux chimiques des Pays-Bas," 1897.

radical constituting the side chain, and the corresponding six by the hydrogen of the CH radical. This hydrogen may be similarly replaced by a $CH_3$ radical, and tetramethyl-methane



is thereby obtained. It will be noted in this case that two of the bonds of the original methane carbon are each formed by four radially equidistant methyl carbon atoms; and the remaining two bonds constituting the side chain are each formed by six radially equidistant methyl carbon atoms.

This variation of the bonds is due to the fact that if a sphere is divided into eight points corresponding to the corners of a cube there cannot be a second set of symmetrical points, eight in number, as there is no regular solid with sixteen faces. It will be noted in every case with the carbon atoms, that when the four points, *b*, meet other similar points of contiguous carbon atoms, as in the compound $CH_4$, then every hydrogen atom may be enclosed for four different facets constituting a single bond; but immediately the points *b* touch *facets* of contiguous carbon atoms the eight corners of a hypothetical cube are occupied, and the remaining single bonds must be formed by six contiguous atoms corresponding to the faces of the cube.

The following homologous series of compounds may be derived from the methane hydrocarbons:

| Hydrocarbon. | Chloride. | Alcohol. | Aldehyde. | Acid. |
|---|---|---|---|---|
| $CH_4$ | $CH_3Cl$ | $CH_3OH$ | $CH_2O$ | $CH_2O_2$ |
| $C_2H_6$ | $C_2H_5Cl$ | $C_2H_5OH$ | $C_2H_4O$ | $C_2H_4O_2$ |
| $C_3H_8$ | $C_3H_7Cl$ | $C_3H_7OH$ | $C_3H_6O$ | $C_3H_6O_2$ |
| $C_4H_{10}$ | $C_4H_9Cl$ | $C_4H_9OH$ | $C_4H_8O$ | $C_4H_8O_2$ |
| &c. | &c. | &c. | &c. | &c. |

By chlorination of the hydro-carbon one or more atoms of hydrogen may be replaced by chlorine; but it is only necessary here to consider the monochlorides. In dealing with the metals it was noted that the metallic mono-, di-, tri-, and tetra-chlorides must have the same atomic arrangement as the hydrides of the acidic elements. Carbon is almost on the border between the metallic and acidic elements, and has an affinity for chlorine as well as for hydrogen. Methyl-chloride $CH_3Cl$ is exactly analogous to ethane $C_2H_6$ or $CH_3—CH_3$; the chlorine atoms of $CH_3Cl$ occupy the same position as described for the second carbon atom in $CH_3—CH_3$, but, being a monad, it simply displaces one hydrogen atom and rearranges the other three to play on the remaining twelve facets of the carbon atoms. Similarly, ethyl-chloride, $C_2H_5Cl$, would be analogous to propane, $C_3H_8$, but the chlorine atom occupies the position of the third carbon atom forming one of the methyl groups $CH_3$.

If the chlorine atom in methyl-chloride, $CH_3Cl$, is replaced by an atom of oxygen the four facets, *a* (Fig. 13), may engage the four radially equidistant carbon atoms, but it also has four additional facets, *b*, which are sufficient to allow of an additional hydrogen atom, and methane alcohol, $CH_3OH$, is thus formed. But the hydrogen in the hydroxyl (OH) is not bound to the carbon atom directly, but only through the oxygen atom. The three hydrogen atoms of $CH_3OH$ no doubt play on the twelve facets of the carbon atoms exactly as described in the chloride $CH_3Cl$; and the fourth hydrogen atom must then necessarily play on one facet, *b* (Fig. 13), of four radially equidistant oxygen atoms, and these oxygen atoms are each attached by the equivalent of one bond to a carbon atom. Such are the primary alcohols.

By oxidation the primary alcohols may be converted into aldehydes, as $CH_2O$, which are chiefly remarkable for chemical activity and capability of further oxidation to acids ($CH_2O_2$), or of deoxidation to alcohols. In formic aldehyde, $CH_2O$, it is at once apparent that with a rhombic dodecahedron

escribing the carbon atom the four points *a* and the four points *b* may be occupied by the hydrogen atoms, while the six points *C* may be occupied by the oxygen atoms in a similar manner to the oxygen atom as described in the ketones. Each oxygen atom with six pairs of facets is surrounded by six carbon atoms, each with a pair of facets, the reverse of the oxygen atom, and capable of engaging with it. When the carbon atoms are arranged in this manner the points *a* come together in fours, and likewise the facets *b*. The edges *C* (Fig. 15) are parallel on opposite carbon atoms, but perpendicular on adjacent carbon atoms surrounding the oxygen atom.

The characteristic atomic group in organic acids is carboxyl, —COOH, and these acids are mono-, di-, tri-, &c., basic, accordingly as they contain one or more of these groups in the same molecule. The structural formula of formic acid ($CH_2O_2$) is H—COOH, and of malic acid ($C_2H_4O_2$) $CH_3$—COOH, and the hydrogen of the carboxyl group is replaceable by metals, as in the inorganic monobasic acids. A comparison of these two acids will show that the bond of the carboxyl group is the same as that between the two methyl groups of ethane $CH_3$—$CH_3$; and this has been already shown to consist of the carbon atoms engaging each other with the four facets, *b*. Therefore in formic acid one hydrogen atom plays on the facets, *b*, of four radially equidistant carbon atoms, and the remaining twelve facets with the points *a* are occupied by the atomic group ≡OOH, of which one oxygen atom is attached to the carbon by a double bond, and the other by a single bond. The oxygen with the double bond must be placed at the six points, *C*, as described in the aldehyde, thus disposing of the twelve facets; so that the remaining oxygen atom must be placed at the remaining points *a* with four facets, *a* (Fig. 13), engaging the points of four radially equidistant carbon atoms, and four facets *b* (Fig. 13) engaging four radially equidistant hydrogen atoms. These replaceable hydrogen atoms each collide with the

facets *b* (Fig. 3) of four radially equidistant oxygen atoms, as previously described in the hydroxyl groups of the alcohols.

The alcohols are divided into monatomic, diatomic, triatomic, &c., accordingly as they contain one, two, or three hydroxyl radicals, but, as these are always attached tc different carbon atoms, no further description is necessary. Two hydroxyl groups could not be attached to one carbon atom, as water would at once be formed. An alcohol is also said to be *primary*, *secondary*, or *tertiary*, accordingly as the carbon atom in combination with the hydroxyl group is linked to one, two, or three carbon atoms, and are severally characterised by the atomic groups —$CH_2OH$, =CHOH, and ≡COH, each formed from their respective hydro-carbon radicals —$CH_3$, =$CH_2$, and ≡CH. It has already been shown that the primary alcohols by oxidation yield aldehydes and then acids; and it can also be at once seen that a secondary alcohol by oxidation would yield a corresponding ketone; but a tertiary alcohol cannot be further oxidised without breaking up the carbon linking, and when this happens a mixture of acids with a less number of carbon atoms is the result.

This practically completes a series of representative compounds of oxygen with the methane or paraffin series of hydro-carbons, and it will be useful now to examine some of the compounds of nitrogen or ammonia as exhibited in the amines, &c.

The alcohol radical, as $CH_3$, $C_2H_5$, &c., may replace an atom of hydrogen in ammonia or ammonium as follows:

| *Ammonia Bases (Amines).* | | | *Ammonium Bases.* |
|---|---|---|---|
| $NH_2(CH_3)$ | $NH(CH_3)_2$ | $N(CH_3)_3$ | $N(CH_3)_4I$ |
| $NH_2(C_2H_5)$ | $NH(C_2H_5)_2$ | $N(C_2H_5)_3$ | $N(C_2H_5)_4OH$ |
| &c. | &c. | &c. | &c. |

In these compounds the relative arrangement of the atoms in the alcohol radicals and in ammonia are exactly known, so

that it is only necessary to show what constitutes the single, double, and treble bond between nitrogen and carbon, and the whole of the amines will be thoroughly comprehended.

In trimethylamine $N{\equiv}(CH_3)_3$ the carbon replaces the whole of the hydrogen in ammonia, and the treble bond must therefore consist of twelve radially equidistant carbon atoms. The four facets *b* of the carbon possibly engage the nitrogen atoms; and their remaining twelve facets are available for the three hydrogen atoms exactly as described for ethane, $CH_3—CH_3$.

In dimethylamine, $NH{=}(CH_3)_2$, carbon can hardly form a double bond with nitrogen by engaging the six pairs of facets *C* (Fig. 14) like oxygen, as described in the aldehydes and ketones, as these pairs of facets are obtuse on both the nitrogen and carbon atoms. The double bond must therefore be formed by twice four radially equidistant carbon atoms which have displaced two-thirds of the hydrogen atoms.

In methylamine, $NH_2—CH_3$, the single bond is similarly formed by four radially equidistant carbon atoms.

The sixteen facets of carbon may be divided into four sets each of four radially equidistant facets tetrahedrally inclined; and likewise the twelve facets of nitrogen may be similarly divided into three sets, so that a set of four may be appropriated for each bond in these compounds whether between carbon and nitrogen, or of either with hydrogen.

Ammonium ($NH_4$) is, of course, only known in combination, and nitrogen is in this case assumed to be pentavalent. It may be noted that besides the twelve facets forming the three bonds, nitrogen has also eight projecting tetrahedra, which may form an additional double bond. In the gaseous form of ammonium chloride the HCl may combine with $NH_3$ by the extra hydrogen atoms occupying four of these points, and chlorine atoms the remaining four. The solid $NH_4Cl$ would be, as previously described (p. 47) with the nitrogen and chlorine, arranged dodecahedrally with hydrogen atoms at the eight solid angles. The solid ammonium chloride is

remarkable for its tough fibrous texture. This toughness can only be due to the motions of its constituent atoms, and when these are thoroughly understood they will no doubt account for the strength of organised tissues being always due to nitrogenous substances. The motion of the monad atoms in $NH_3$, and also in gaseous $NH_4Cl$, is certainly remarkable, as three hydrogen atoms all seem to pass through the eight points *a* and *b* (Fig. 14), being guided thereto by the various facets, while the HCl atoms are also enclosed at these same points.

Tetramethyl ammonium iodide $N(CH_3)_4I$ is a solid and must have an atomic arrangement similar to $NH_4Cl$; but three of the four sets of facets of each carbon atom are utilised for further combination with hydrogen in the radicals $CH_3$, while the fourth set of each forms the original bond with the nitrogen atoms.

## AMIDES.

The hydroxyl in an acid radical, as $C_2H_3O—OH$ (acetic acid), may be replaced by $NH_2$ to form acetamide, $C_2H_3O—NH_2$. The acids have been already described, and it can be seen that if the nitrogen atom takes the place of oxygen it has two sets of four facets available for further combination with two atoms of hydrogen, while the oxygen in the same position has only one set of facets, which is equivalent to only one hydrogen atom in the hydroxyl.

As the same kind of reasoning applies to all the numerous organic compounds in which nitrogen enters, it is unnecessary to describe them further; but it will be interesting to see the atomic arrangement of that powerful explosive, nitro-glycerine:

## NITRO-GLYCERINE.

Glycerine, $C_3H_5(OH)_3$, is a triatomic alcohol.

Glycerine. Nitro-glycerine.

And the exact spacial arrangement of its atoms has already been sufficiently described in the open-chain methane series and the alcohols derivable therefrom. Nitro-glycerine has the hydrogen atoms of the three hydroxyls replaced by $NO_2$. One set of four facets (or perhaps the corners) of nitrogen engage the four facets of oxygen previously occupied by hydrogen, and the other facets are available for the two atoms of oxygen, but it is not accurately known whether the nitrogen in this case is pentavalent or trivalent, and whether each oxygen atom is connected to it by the equivalent of one or two bonds. The explosive nature of this substance is, of course, due to the unstable character of the nitrogen bonds; but the large amount of latent energy stored in this compound must be entirely due to the motions of its constituent atoms suddenly resolved into an expansive force during an infinitely small period of time. A great part of this is no doubt due to the hydrogen falling into the spaces formed by the oxygen atoms and producing the gaseous formation of water; and carbon di-oxide ($CO_2$) may be similarly formed.

## ETHERS.

If water is separated by heating with sulphuric acid or otherwise from two molecules of a monatomic alcohol, as $2(C_2H_5—OH)$, an ether is the result $(C_2H_5—O—C_2H_5)+H_2O$. In describing the alcohols it was shown that the oxygen atom had four radially equidistant carbon atoms and four radially equidistant hydrogen atoms, constituting the double bond. It can at once be seen that the hydrogen is replaced by a carbon atom of the second molecule, and the oxygen is

the connecting link which forms the two into one molecule. It has been previously stated that two hydroxyl groups cannot be attached to one atom, as water is thereby formed, and this is the same reaction, but between different molecules.

Ethers can also be formed between different alcohol radicals, or with an alcohol and an acid radical. Nitroglycerine, just described, is an ether of nitric acid, and this may account for its unstable character, as the $NO_2$ radical is merely a residue caused by the formation and abstraction of water, and not by its own combining capacity.

### OLEFINE SERIES ($CH_2 + nCH_2$).

This series contains two atoms of hydrogen less than the methane series, and the lowest member is $C_2H_4$ or $CH_2=CH_2$. A methylene ($CH_2$) does not exist. The members of this series combine readily with two monad elements or radicals to produce members of the methane series or their derivatives, such as alcohols, acids, &c., from which it is concluded that they are similarly linked in an open chain, each additional $CH_2$ radical forming a link in the chain as before. But by comparing the bonds of the carbon atoms of the two series, as deduced from chemical considerations, it will be seen that the regular valency of the open chain is disturbed thus:

*Methanes.*

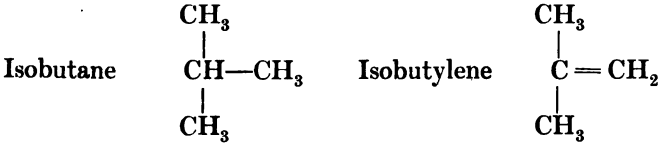
| | |
|---|---|
| Ethane . . . | $CH_3—CH_3$ |
| Propane . . | $CH_3—CH_2—CH_3$ |
| Butane . . . | $CH_3—CH_2—CH_2—CH.$ |

*Olefines.*

| | |
|---|---|
| Ethylene . . | $CH_2=CH_2$ |
| Propylene . . | $CH_2=CH—CH_3$ |
| $\alpha$-Butylene . . | $CH_2=CH—CH_2—CH_3$ |
| $\beta$-Butylene . . | $CH_3—CH=CH—CH_3$ |

This comparison is made between the normal compounds only,

but butane and butylene also form isomeric modifications with side chains, thus:




The spacial arrangement of the atoms in ethane, propane, butane, and isobutane of the methane series have been clearly described, and with the aid of the structural formula the spacial arrangement in the corresponding olefines should be easily obtained. For instance, in ethylene there is a double bond between the carbon atoms, while in ethane there is only a single bond. Every carbon atom in ethylene must therefore have eight radially equidistant carbon atoms instead of four, as in ethane, and this rearrangement of carbon will account for the reduction in the number of hydrogen atoms.

The olefine series is remarkable for its capability of forming another series, as trimethylene, tetramethylene, hexamethylene, &c. These contain, instead of the open chain of the olefines, a closed chain, thus:

These compounds are allied to the benzene series, and the spacial arrangement of their atoms will be inferred from the description to be presently given of benzene, $C_6H_6$.

## ACETYLENE SERIES ($C_2H_2+nCH_2$).

This series contains four atoms of hydrogen less than the methane series or two less than the olefines; and the lowest member is acetylene $C_2H_2$, or CH≡CH. The acetylenes like the olefines are unsaturated and are capable of combining with two or four monad elements or radicals to form olefines

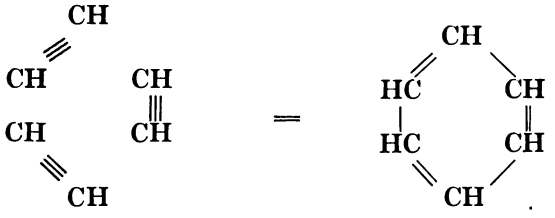
and paraffins (methane series) or their derivations. A characteristic of the acetylenes is that they form triple bonds between carbon atoms and, therefore, as in the case of the olefines, more than one constitutional formula is possible, thus:—

| | | |
|---|---|---|
| $C_2H_2$. | $CH{\equiv}CH$ | |
| $C_3H_4$ | $CH{\equiv}C{-}CH_3$ | $CH_2{=}C{=}CH_2$ |
| $C_4H_6$ | $CH{\equiv}C{-}CH_2{-}CH_3$ | $CH_2{=}CH{-}CH{=}CH_2$ |

It is remarkable that where there is a triple bond between the carbon atoms that molecule is capable of forming unstable metallic compounds, as $C_2Cu_2$, $C_2Ag_2$, $C_3H_3Ag$, $C_2HNa$, $C_2Na_2$; but if the group $-C{\equiv}C-$ should be linked on both sides to carbon atoms it cannot form metallic compounds as there is no replaceable hydrogen. To obtain the spacial arrangement of the atoms in acetylene compounds and in what manner they differ from the olefines and paraffins, it is only necessary to know in what the triple carbon bond consists. For this purpose acetylene ($C_2H_2$) alone may be considered. The gaseous arrangement may be with two points, *a* (Fig. 15), meeting together in place of four, as described for methane. In this case two atoms of hydrogen are enclosed by eight facets, *b*, on eight different carbon atoms, each hydrogen atom playing on an alternate set of four facets, like a dibasic inorganic acid, as in gaseous $SH_2$ or $H_2O$, or in the liquid $H_2SO_4$. This formation will account for the double molecule, as the molecule CH is unknown.

## BENZENE SERIES.

Three molecules of acetylene $C_2H_2$ (just described) will polymerise into benzene $C_6H_6$:—




in which the six hydrogen atoms have an equal value and the six carbon atoms are apparently connected in the form of a ring. But the six carbon atoms are not held in position by their own bonds with each other so much as by the action of the six hydrogen atoms or their substituents.

Phenol, $C_6H_5$—OH has one hydrogen atom replaced by hydroxyl, and it will be convenient to find a possible arrangement for the atoms of such a compound.

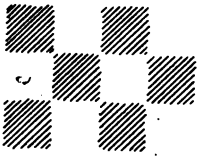


FIG. 16.

Imagine space to be divided into cubes as in Fig. 16 with a carbon atom within one half the cubes (shaded). The four points *a* (Fig. 15) of each carbon must point to four alternate corners of the escribed cube and the four facets *b* will point to the other four alternate corners. If in each empty cube the six edges *c* (Fig. 15) of each carbon atom surrounding the empty cube are parallel on opposite sides but at right angles to those on adjacent sides, then at one half of the corners of the cubes (Fig. 16) four points, *a* (Fig. 15), will meet, and at the alternate corners four facets, *b*, will face each other; and this is the position to insert the hydrogen atoms. As each hydrogen atom touches four carbon atoms and each carbon atom likewise touches four hydrogen atoms the proportions of each are equal and may represent the compound $C_6H_6$, provided the replaceable hydrogen atoms can be separated into groups of six, and this may be conveniently shown by means of phenol $C_6H_5OH$.

By using Fig. 16 in a different manner the position of the hydrogen atoms alone may be represented by the same cubes and the carbon atoms may be considered as occupying four alternate angles of the eight corners of each cube. The four facets *b* will point to the centre of each of the hatched cubes containing the hydrogen atoms, and four points *a* of four different carbon atoms will point to the centre of each of the

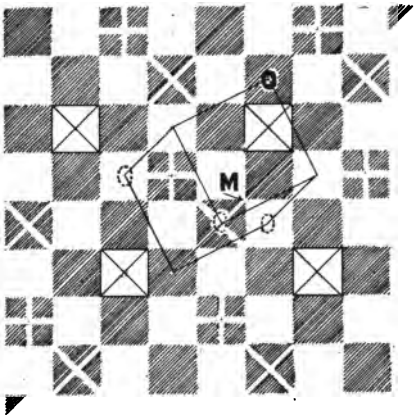



FIG. 17.

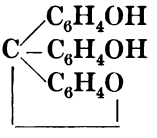
empty cubes. The arrangement is exactly the same but the point of view is different.

In Fig. 17 the hatched cubes again represent the hydrogen atoms which may all be divided into groups of six like a cubic Maltese cross with six arms as in Fig. 19. Each black cross (Fig. 17) connects four hydrogen atoms in the one plane and indicates the position of the two others, one above and the other below; and similarly each white cross connects four hydrogen atoms in the next plane above or below (alternately) and indicates the position of the two others. It will now be found that all the hydrogen atoms are accounted for as in the plane shown all the hatched cubes not one of four touching a black cross are occupied by a white cross; and similarly in the next plane above or below,

one half the hatched cubes, not one of four touching a white cross, are occupied by a black cross.

Now if an hydrogen atom of each cubic Maltese cross is replaced by an oxygen atom, the four facets *a* of the oxygen (Fig. 13) will be satisfied by the four carbon facets vacated by the hydrogen atom but it also adds four additional facets, *b*, to the compound; and as these oxygen atoms (as will be immediately shown) are arranged tetrahedrally to each other like the alternate angles of a cube, the hydrogen atoms of the hydroxyl are entirely held by and play freely between the facets *b* of the oxygen atoms and a point such as **M** (Fig. 17) the centre of four oxygen atoms is an alternate one that contains no carbon atom in the way of the hydroxyl hydrogen, and therefore the atoms and atomic bonds in phenol $C_6H_5OH$ are fully accounted for.

If an additional carbon atom is placed at this point **M** (Fig. 17) its four facets *b* (Fig. 15) may point to the similar facets *b* of the oxygen atoms (Fig. 13) and its four points *a* would point to the centre of the adjacent empty cubes, so that every three facets *C* adjacent to the points *a* would each engage a facet *b* of a carbon atom belonging to the original phenol group. As there are twelve of these facets on the methane carbon so engaged, it follows that three atoms of hydrogen have been displaced from the adjacent phenol groups just as required by the empirical formula of aurin :—




It is known from chemical considerations that the hydrogen atom displaced from each of the three phenol groups is in the *para* position to their oxygen atoms and as in Fig. 17 four different phenol groups meet at the point **M**, the position of four oxygen atoms can be seen to be radially

equidistant from this point, and are indicated by the letter O. These four oxygen atoms are in the alternate angles of the rhombohedron shown, with the methane carbon near its centre, and on the faces of this rhombohedron (or approximate cube) others can be assumed to indicate the position of all the oxygen atoms.

In aurin one-third of the hydroxyl hydrogen atoms only

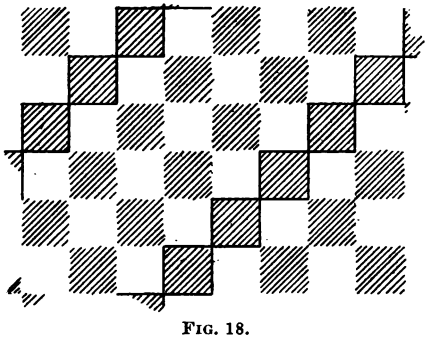
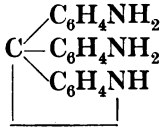


FIG. 18.

are eliminated and if the relative positions of these hydrogen atoms are considered alone they may be represented by the hatched cubes in Fig. 18. If one-third of each plane section is displaced by a carbon atom such carbon atoms must apparently run in straight lines as shown by the full-lined cubes. Exactly the same arrangement is obtained by displacing every third tier.

Aurin is a typical compound from which the principal aromatic compounds may be obtained. For instance in anhydrous para-rosaniline,




the atomic arrangement is exactly the same except that hydroxyl is replaced by amidogen ($NH_2$). The nitrogen

atom takes the position occupied by oxygen and its superior number of facets enables it to carry an additional hydrogen atom, exactly as it does in its binary compounds. Similarly, in para-leucaniline,

$$C(H)\begin{cases}C_6H_4NH_2\\ -C_6H_4NH_2\\ C_6H_4NH_2\end{cases}$$

the hydrogen atom of the methane carbon plays on the facets *b* (Fig. 15) of four different methane carbon atoms.

The atomic formation of the following mother substances may likewise be obtained from those already described:—

Tri-phenyl-methane $CH\begin{cases}C_6H_5\\ -C_6H_5\\ C_6H_5\end{cases}$

Di-phenyl-methane $CH_2\begin{cases}C_6H_5\\ C_6H_5\end{cases}$

Toluene $CH_3—C_6H_5$

Di-phenyl $C_6H_5—C_6H_5$

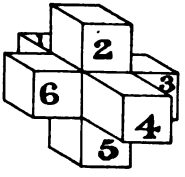
More complicated compounds, such as the naphenes, should present no difficulty, provided the empirical formula is correctly deduced.

It would be interesting and quite feasible to delineate the triphenyl-methane series of dyes, noting the change of colour due to each alteration of structure. It may be found that the distance between the parallel planes containing the methane-carbon atoms is equal to the wave-length of a particular ray of light.

If the hydroxyl group in phenol ($C_6H_5OH$) is replaced, by carboxyl, —COOH, to benzoic acid, the carbon would occupy the position of the oxygen, and the two oxygen atoms, with the hydrogen atom, would be arranged exactly as described for the fatty acids; that is to say, one oxygen atom has four facets engaging the carboxyl-carbon atoms, and the remaining four engaging the acidic-hydrogen atom; while the oxygen

atom bound by two bonds to the carbon surrounds it on six sides as described in the aldehydes and ketones.

The *ortho*, *meta*, and *para* positions in the benzene nucleus can be determined when it is known that the six hydrogen atoms of benzene are arranged relatively to each other in the form of a cubic six-armed Maltese cross, and that the 1-4, 2-5, and 3-6 positions are on opposite sides, as in Fig. 19.



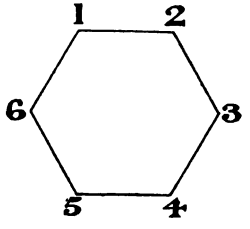




FIG. 19.

Contemplating these complicated organic compounds, it becomes more and more apparent that the net result of all the atomic motions (as was indicated in the description of ammonia) is continually to form molecules at every atomic instanta t four different points corresponding to the corners of a tetrahedron, each molecule being continually formed by a different set of atoms. In Chapter II. the existence of molecules as at present conceived is disproved; but, as is often the case in scientific investigation, what is considered to have been entirely disproved may be found to contain a modicum of truth. The number of atoms meeting at each of the four points is the number forming one molecule; and in this way trimethylene, tetramethylene, hexamethylene, &c. (p. 88), and other polymers may be accounted for. With benzene it is also evident that at the points referred to the atoms of one molecule may approximate to the theoretical ring formation of Fig. 19. There is ample scope here for the mathematician.

## CHAPTER VIII.

### UNASSIGNED ATOMS.

THERE are several very definite atomic shapes that have not yet been assigned as the atoms of any particular element.

Between hydrogen and lithium there is only one such definite shape. This model has a central tetrahedron with an additional projecting one attached on each of its four faces, and as it contains five tetrahedra its atomic weight would be 2·5. This atom can only be assigned to helium, whose atomic weight was at one time considered to be rather more than 2, but lately as more likely to be 4. Helium is very remarkable for its highly refractive power and an examination of this atomic model will show that the angles formed by adjacent facets are totally different from any other atom hitherto described. It is remarkable that there is no other known element with an atomic weight intermediate with hydrogen (1) and lithium (7).

An unknown atom, whose shape is an icosahedron, with an atomic weight of 10, occurs between beryllium, 9, and boron, 11, and this may be provisionally named "icosagon." It would be a metal much more volatile than zinc, cadmium, or mercury, and would differ from beryllium about as much as zinc differs from copper, or cadmium from silver, or mercury from gold.

Another atom, with an atomic weight of 20, may be formed by attaching tetrahedra to the twenty facets of "icosagon." This atom would be very similar to fluorine, 19, and also to the other halogen elements, and might reasonably be expected to be exceedingly active. It is possible that

it is so much like fluorine that it has not been isolated from it, and fluorine is therefore a mixture of the two atoms. It is also just possible that this No. 20 atom approximates so nearly to a rhomboidal dodecahedron that its very activity causes it to combine only with its own atoms, and there is no residual valency by which this combination may be broken up, as is the case with all other elementary molecules. Only by such a supposition can this element be reconciled with that inert element "argon," whose atomic weight is supposed to be 20.

There are also two atomic shapes which would naturally terminate the series No. 9, and the metallic series No. 10 respectively. The former with an atomic weight of 215 would be allied to the halogen elements by its formation at the poles and may, therefore, be called provisionally "x-odine"; but by its formation at the girdle-belt it would be much more metallic in characteristics. The other atom, which may be called "zadmium," represents an atomic weight of 245, and would be allied to mercury. It would indicate the existence of a whole series of metals, of which thorium and uranium are the only known examples; and the individual members of such a series would be scarcely distinguishable in characteristics from osmium, iridium, platinum, gold, and mercury respectively, as the relative size and atomic shape of each analogue would not greatly differ. This may be a reason for the diversity of different determinations of the atomic weights of the metals osmium, iridium, platinum, and gold.

There is yet another atomic shape unaccounted for. Hydrogen is built up of two tetrahedra: where is the element corresponding to an atomic weight of one-half, and whose atom is a tetrahedron? It has been calculated that if there were any free hydrogen in the atmosphere it would long ago have left this planet by its superior diffusive power, and the kinetic energy of the gas would have overcome the attraction of the earth. The same reasoning would still more apply to an atom of one half the weight. The ether pervades all space,

and when excited by light, heat, electricity, or gravity, it is capable of influencing the motion of material atoms, as exhibited in the action of the sun on a growing plant, or in the vaporisation of water, or in the attractions of the spheres. If the ether is capable of moving a material atom, it must itself occupy space, and this it can only do atomically; which is to say that it is itself matter, and the atom of the ether may be represented by the tetrahedral atom one-half the *mass* of the hydrogen atom. Heat is purely atomic motion, and as this motion is transmitted across space from the sun to the earth, then, as far as the ordinary powers of observation will allow one to draw a conclusion, that motion must be transmitted by atoms which effectually occupy space. It by no means follows that these tetrahedral atoms are one-half the *weight* of hydrogen, as, if not themselves the origin or reservoir of gravitative forces, they are the means by which these forces are transmitted, and may, consequently, be themselves imponderable. Heat, light, and electricity are continually being dissipated in space. Whence do these forces go if they are not stored up in the atoms of the ether? It may be objected that material atoms would cause friction on the external surfaces of the planets or their envelopes, and thus cause their motions to speedily cease; but these tetrahedral atoms may have peculiar motions, which would make them into a veritable ocean of perfectly balanced friction rollers, moved by an independent source of power, so that they would have no retarding influence whatever. It is also possible that in an ocean of such universal motion an atom at comparative rest (through being joined within any mass to other atoms) would have free atoms impelled or attracted towards it by the action of the contiguous atoms of the ether. Such a theory of gravity is at least the only one yet advanced or suggested with a practicable source of power behind it; but the purpose now is simply to assign the position of the tetrahedral atoms which were also assumed to be the atoms of the primordial material.

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